AL-TR-1992-0007

AD-A263 609

PROGRESS IN THE PSYCHOPHYSIOLOGICAL ASSESSMENT OF WORKLOAD

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93-10308

INTERIM REPORT FOR PERIOD 1 OCTOBER 1987 TO 30 SEPTEMBER 1991

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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AL-TR-1992-0007

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Kenneth R Boff

KENNETH R. BOFF, Chief
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REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Oct 1991	Interim, 1 Oct 87 to 30 Sep 91

4. TITLE AND SUBTITLE

Progress in the Psychophysiological Assessment
of Workload

6. AUTHOR(S)

Wilson, Glenn F., PhD

5. FUNDING NUMBERS

PE 62202F
PR 7184
TA 14
WU 25

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Crew Systems Directorate,
Human Engineering Division, AFMC, HSC
Wright-Patterson AFB OH 45433-6573

8. PERFORMING ORGANIZATION REPORT NUMBER

AL-TR-1992-0007

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release;
distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)   This report is a review of the efforts of the Workload and Ergonomics Branch in the area of psychophysiological measurement of human cognitive workload. Three areas are covered: flight studies, laboratory electrophysiological research, and the magnetoencephalography laboratory. This includes current progress and future directions in these areas. Physiological data have been used to monitor crew workload in three flight studies and have provided a wealth of data. Evoked brain activity, heart rate, heart rate variability, eyeblinks, and respiration have been used to determine the cognitive workload of crew members. In the laboratory, topographic mapping of brain evoked potentials and ongoing brain activity have been used to study cognitive task difficulty. Heart rate, heart rate variability, eyeblinks, and respiration are also used. We are developing a clear picture of the effects of cognitive task difficulty on these physiological measures to the point that we have begun to classify cognitive tasks on the basis of these data. The work in the magnetoencephalography laboratory permits us to have a better understanding of brain function during cognition. Evoked fields have been used to study cognitive activity using the probe paradigm and the brain's processing of sensory information.

14. SUBJECT TERMS
Psychophysiology, workload, heart rate, evoked response, eyeblinks, flight recording, magnetoencephalographic brain mapping, cognition

15. NUMBER OF PAGES
75

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

PREFACE

This technical report reviews the progress of the Armstrong Laboratory psychophysiological workload effort in the Human Engineering Division at Wright-Patterson Air Force Base. This summary covers the work of the past several years and encompasses both basic and applied research efforts. A broad based approach has been used to address the questions of understanding and measurement of operator workload using psychophysiological measures. Heart, eye, respiration and brain measures have been used to determine the best use of each one. Further, measures have been combined to take advantage of the strengths of each one when used in combination.

Considerable progress has been made by this effort in both the laboratory and flight environments. The studies reported here have increased our understanding of operator workload and the relationship of the various physiological measures to operator state. Physiological measures are maturing to the point where they are being used by the design and test and evaluation communities. In addition to publications, a second generation psychophysiological test battery has been developed for use by other investigators who wish to employ these methods in their own work. The development of the test battery supports our goal of increasing the use of physiological measures in the applied arena.

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INTRODUCTION

The measurement and monitoring of operator state is becoming more important as the systems that humans are required to operate become more complex and place greater demands on the operator, on one hand, and are more automated and boring on the other. Airlines currently schedule commercial passenger flights of 14 hours or more on highly automated aircraft which primarily requires monitoring by the crew. The modern fighter aircraft with its multifunction displays can present an overwhelming amount of information to the pilot, and its complex control and weapons systems require a taxing array of information processing and decision options. In these environments, workload and fatigue are important factors and we must understand these phenomena and derive measures that allow us to monitor them so that dangerous situations can be avoided. This is true of high and low workload situations, as well as fatigue and boredom conditions. All of these states can result in serious consequences if they are not detected in time to take corrective actions. The same understanding of the phenomena and requirement for measurement tools are also needed in design, display evaluation, simulation, and operational test and evaluation.

Traditionally, three approaches have been taken to measure operator workload and state: (1) performance, (2) subjective and (3) physiological measures. Each method has its strengths and weaknesses and a combination will no doubt constitute the best approach. Performance measures, when available, can

produce large quantities of data whose use is problematic since there is no agreement about which measures are best. Often direct performance measures cannot be made, especially in the case of operational aircraft that are not instrumented to provide the relevant data. Even when data are available, the large number of correct ways to accomplish a given mission make it difficult to know how to score performance data. Further, under extremes of high or low workload conditions, the operator may fail to respond at all. Secondary task methodology has been used to gather performance data, but the secondary task may interfere with primary task performance or its performance may be omitted under extremes of primary task workload. Subjective techniques are used a great deal, exclusively in some situations, and provide useful data. However, these data are subject to errors of memory and can be influenced by operator bias. If the subjective evaluations are collected during task performance, they are susceptible to the same problems of intrusion as the secondary task techniques.

Physiological data can be collected non-intrusively in terms of the primary task since the physiological activity is ongoing simultaneously with the performance of the task. Physiological data can be collected continuously making it possible to monitor subject state in rapidly changing environments and to reduce the problem of missing important episodes due to lapses in data collection. Physiological data recording does require specialized equipment, but the current state-of-the-art in electronic hardware and computer software

makes this a relatively minor problem. Other physiological signals can interfere with those of interest, e.g., eye blinks intruding onto EEG, but there are methods available to deal with these problems.

The psychophysiological laboratory of the Armstrong Laboratory, Workload and Ergonomics Branch has made considerable progress in the past several years. The goal of our efforts has been to provide a better understanding of operator state by using physiological measures and to develop a database of both laboratory and field data so that on-line measurement of operator state can be accomplished during normal duty. This report covers progress over the past several years and discusses future directions. Our efforts encompass a wide range of research and application areas. The field efforts are directed towards utilization of psychophysiological methods to evaluate operator workload and state. Our laboratory work is aimed at developing new psychophysiological methods, validating currently available methods for use in "real world" situations, and providing new knowledge upon which to base future work. The goal of our basic research effort in the MEG and EEG laboratories is to increase the knowledge base of how the brain works and to better understand human information processing, especially during cognition. Progress in each of the major areas will be presented and possible future directions will be discussed. To summarize our activities the most important results will be highlighted.

CURRENT PROGRESS

FIELD RESEARCH

Data have been collected and analyzed from crew members while flying three different types ⸤ aircraft, A-7, B-1 and F-4. These aircraft provide varied environments which include single seat, low level attack aircraft (A-7), fighter-bomber (F-4) and multicrew, low-level bombers (B-1).

A-7 Data

The A-7 study afforded us the opportunity to use physiological data to better understand the workload experienced by single-seat aircraft pilots during different segments of training missions. Heart rate and eye blink data were recorded while the pilots flew in three different flight positions. Each pilot flew in the lead and wing positions of four ship training missions and they also flew the same mission in a simulator. This unique study provided, for the first time, data from the same pilots in these different roles. To our knowledge flight <u>and</u> simulator data recorded from the same pilots have not been reported previously. These data show the effects of the varying workload associated with the mission and also the demands of the three different roles. Figure 1 illustrates the mean heart rate data and shows the effects of the different mission segments (e.g., takeoff, range, cruise) and the differences between flying lead, wing or in the simulator. Flight segments with higher workload were associated with higher heart rates e.g., takeoff, bombing range and landing. The simulator data did not produce significant

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effects on the pilots' heart rates across the mission segments. With regard to the effects of flight position, the lead position demonstrated the highest heart rates, with the wing next, and the simulator flight lowest. The pilots' blink rates
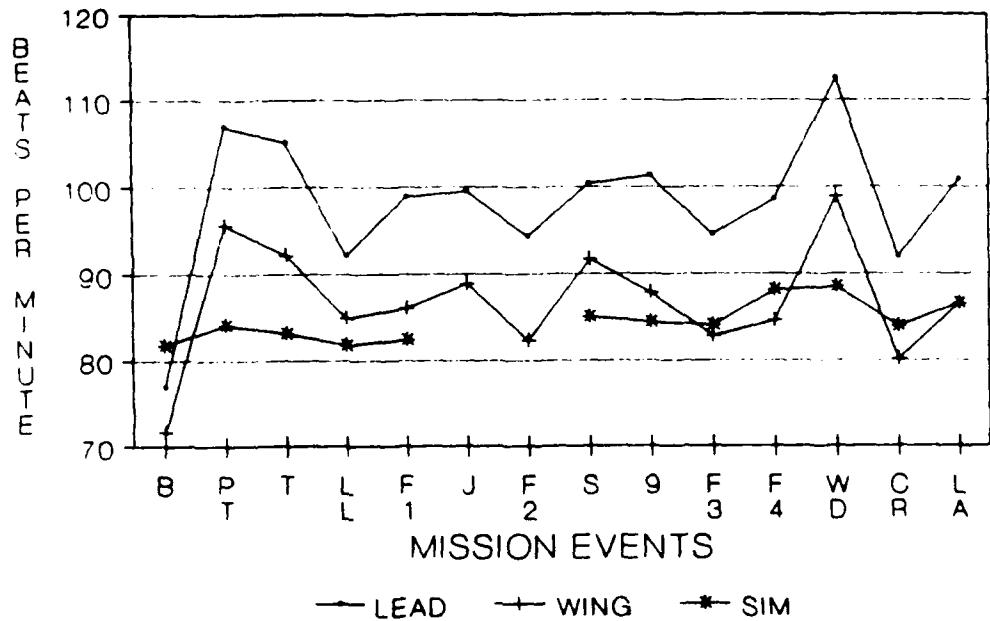
Figure 1. Mean heart rate for the eight A-7 pilots when they flew lead, wing or simulated air-to-ground missions. The highest heart rates were during the missions when they flew lead with wing next highest and simulation lowest. Note the relative lack of change due to mission segment in the simulated mission. The abbreviations for the mission segments represent the following: B - preflight briefing, PT - pre takeoff prior to aircraft roll, T - takeoff, LL - low level flight, F1 to F4 - inflight baselines, J, S and 9 - G maneuvers, WD - weapons delivery at the bombing range, CR - cruise back to base, LA - landing.

were significantly reduced by flying in the wing position which requires greater overall visual attention since one's position relative to the lead aircraft must be maintained in addition to the other requirements of flight (Wilson, et al, 1987).

Serendipity provided us with another unique and valuable set of data. Two of the pilots experienced inflight emergencies and two other pilots experienced emergencies during the simulated flight. These data permit us to examine pilots' physiological responses to potentially life threatening events and allowed us to compare these responses with those during normal flight segments. Both of the inflight emergencies were associated with an approximately 50% increase in heart rate about one minute following the event in both pilot's, even though their flying base rates were different, (86 bpm and 70 bpm). After reaching the peak level, the heart rates of both pilots returned to pre-emergency levels within 60 to 90 seconds. The short recovery time following these major incidents reflects the high quality of the skill and training of the pilots. The data from one pilot are depicted in Figure 2. This type of event cannot be planned, and we were fortunate that we were collecting data when it happened. In contrast to the flight emergencies, the simulator emergencies, both "crashes," produced no increase in heart rate. Consequently, since the simulator emergency produced no effects, it seems that the only way to gather this type of data is by being there when the event occurs (Wilson, Skelly & Purvis, 1988).
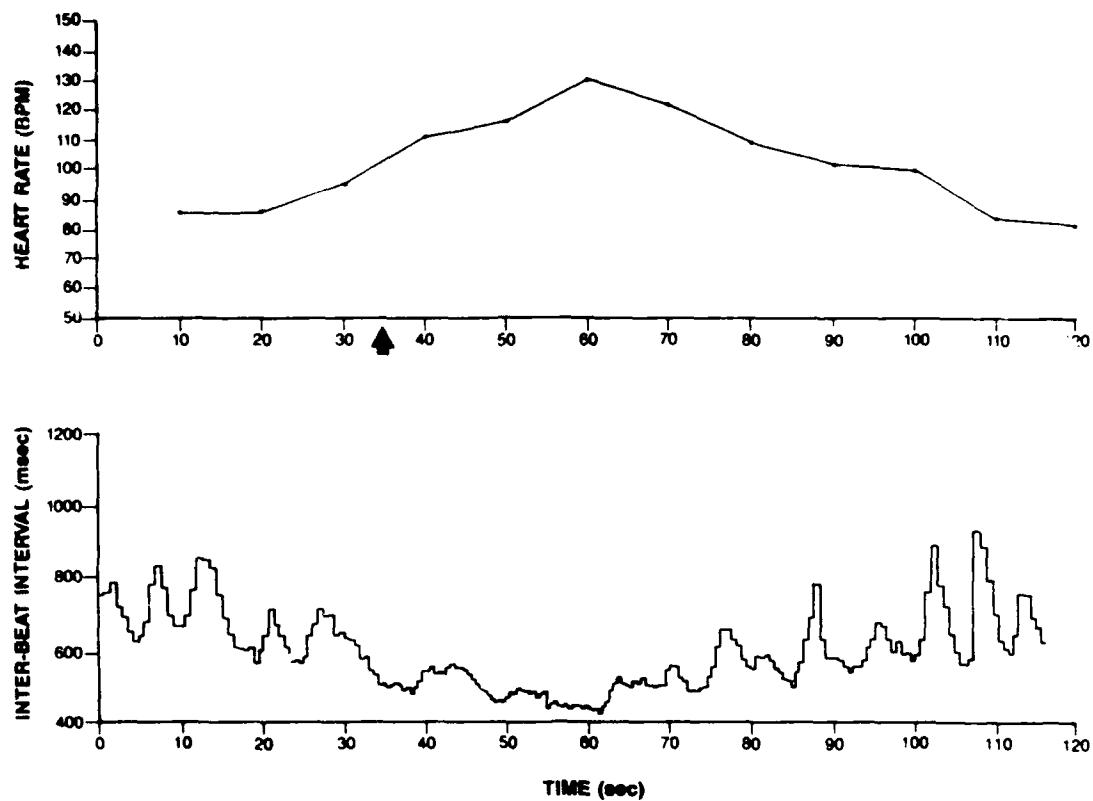
Figure 2. Cardiac responses to inflight emergency - bird strike. The upper graph shows the mean heart rate for 10 second epochs. The arrow designates the time of the bird strike. The lower graph depicts the interbeat intervals during the episode. Smaller interbeat intervals reflect increased heart rate. Note, in the lower graph, that there is more variability in the interbeat intervals before and after the strike and very regular interbeat intervals during and immediately after the strike.

These results demonstrate that physiological data can be used to measure the effects of varying workload levels found during flight and that the effects of the pilot's position in a flight formation has effects upon his physiological data. The emergency data give us insight into the changes that occur and

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their time course when real emergencies happen and are resolved. These data also provide a contrast between actual flight and simulated flight. While the circumstances of the simulation were not ideal, it is clear that simulation does not have the same effects as actual flight. Different simulations or a different simulation environment might produce more varied results but these data do show us that simulation and flight effects can be quite different and that these effects can be measured with physiological data.

B-1 Data

Data collected during B-1 flights represent the first time that physiological data have been collected from bomber crew members, or any crew members, during Green Flag exercises. This is a very realistic exercise which simulates actual combat with multiple aircraft, which represent both friendly and hostile forces. Not only was this the first time the B-1 participated at Green Flag, but the test environment was unique. These data showed the effects of "combat" on aircrews in a new and realistic situation. The heart rate and eyeblink data from this study provided evidence concerning crew members' reactions to the stress of and anticipation of "simulated war" as well as their reactions to the workload of the different mission segments. This is an interesting situation since only training missions are usually available for data collection and one must postulate what the effects of the "real" mission will be. Figure 3 shows mean heart rate from five crew members during their mission of flying to the bombing range, entering

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the range, then orbiting outside the range, re-entering the
range and finally returning to base. The effects of the
bombing range segments and the anticipation of entering the
range are noteworthy in this study. These data represent the
first Green Flag mission for all five crew members and the
anticipation of entering the target area for the first time is

HEART RATE (BPM)

MISSION SEGMENT
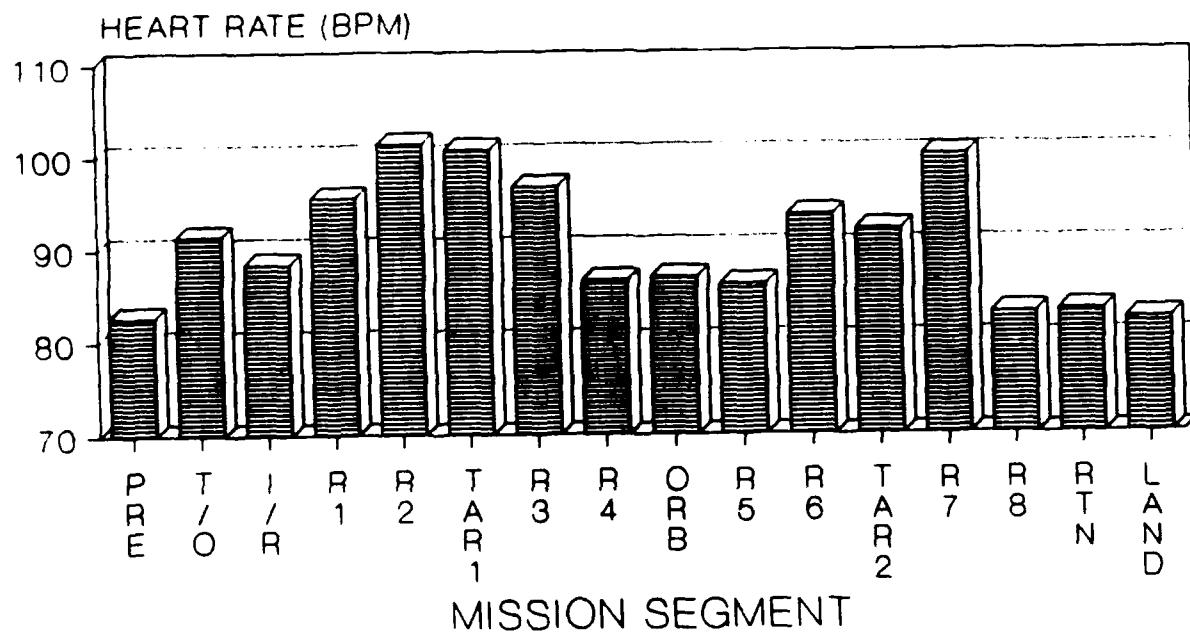
*Figure 3. Mean heart rates for five B-1 crew members
recorded during Green Flag exercises. Note the steady increase
in heart rate beginning with the enroute segment and peaking at
the bombing range when over the target and decreasing with the
last two range segments. The second bombing range segment did
not show the same anticipation. The key for the mission
segments is: Pre - pretakeoff check lists, T/O - takeoff, I/R
- enroute to the range, R1 to R8 - segments in the bombing
range, TAR1 and TAR2 - over the target, ORB - orbiting between
runs on the range, RTN - return flight to base, LAND - landing.*

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seen in the steady increase in heart rate as they approached the range. This effect is reduced after the first range run and the initial heart rates prior to the second bombing run are lower. The range segments themselves were associated with high heart rates.

F-4 Data

The F-4 project was designed to study the effects of air-to-ground training missions on both of the F-4 crew members. Since the F-4 crew consists of a pilot and a weapons systems officer (WSO), we could study the effects of being in the same place at the same time on two crew members with different duties. Their workload varies separately as a function of mission segment due to their different jobs. Although they work together, the two crew members have different responsibilities with different demands. We also collected data while the crews performed a laboratory tracking task prior to the flight. This task has previously been used in the laboratory to study workload because it has some of the attributes of flying. With this data, we can compare each crew members' laboratory data with their flying data and gain insight into just how much the laboratory data can tell us about their responses during actual flight. This will be very helpful in evaluating laboratory data for its usefulness to flight situations. As can be seen in Figure 4, there were large effects on heart rate for both the pilots and WSOs due to the different flight segments. The range produced the largest changes with a mean increase of 31 beats per minute (bpm),

which is a 45% increase over the baseline level for the pilots. This change was no doubt due to the increased cognitive workload, the increased physical activity and the increased G-forces. All of the flight segments did not cause the same level of change in the heart rates. In fact, the heart rate changes correlated very well with subjective estimates of mental workload for the flight segments. The increases in the pilots' heart rates were larger than those of the WSOs, illustrating the higher demands of piloting the aircraft. The one noteworthy exception was during the segment in which the WSO was actually flying the aircraft (CE) which produced a larger increase in the WSO heart rates than that of the pilots. This effect is similar to that reported with pilots and copilots in multicrew aircraft when the pilot in control of the aircraft shows a higher heart rate than when the other pilot is in control.

The laboratory task vs flight comparisons were very informative. The main difference was the magnitude of the changes in the physiological data. The pilots' heart rates increased an average of 3 bpm (5%) during the tracking task compared to the baseline condition, but increased an average of almost 11 bpm (16%) while going over the preflight check lists. Takeoff was associated with a 20 bpm (30%) increase and the mean during the range segments approached 100 BPM (45%). The magnitude of the increase was much larger during the flight segments than during the tracking task suggesting that the cardiac dynamics were quite different.
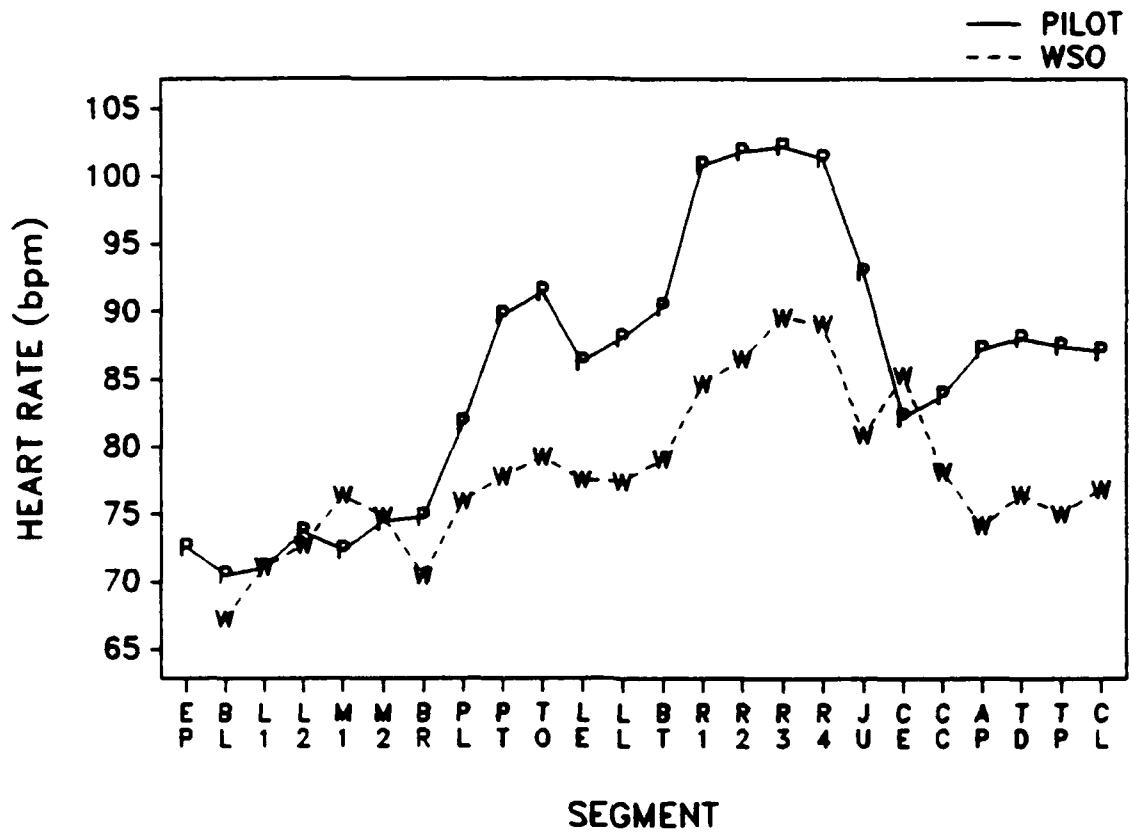
Figure 4. Mean heart rates for the 10 F-4 pilots and 10 F-4 WSOs. During the air-to-ground training flights, the pilots' heart rates were higher than the WSOs, even though their baseline heart rates were approximately the same. The one exception during flight is segment CE when the WSOs were flying the aircraft. Note that the pilot and WSO heart rates were essentially identical during the ground-based tracking task. Two minutes of data were averaged together for each data point. The segment abbreviations are: EP - pilot only, evoked potential baseline, BL - resting baseline, L1 and L2 - low difficulty level tracking task, M1 and M2 - medium difficulty level tracking task, BR - preflight briefing, PL - preflight

check lists, PT - pretakeoff prior to aircraft roll, TO -
takeoff, LE & LL - low level flight, BT - G maneuver, R1 to R4
- bombing range, JU - join-up after range, CE - cruise back to
base WSO flying, CC - cruise back to base pilot flying, AP -
approach to landing, TD - touchdown, TP - following touchdown,
CL - post flight check lists.

The eye blink data were also very different between the
laboratory and flight environments. The laboratory tracking
task, which is a single, visual task, actually produced an
inhibition in the blink rate, as shown in Figure 5. The blink
rate is normally in the vicinity of 20 to 25 blinks per minute.
During the tracking task, the mean blink rate for the WSOs was
less than five blinks per minute. One WSO blinked only one
time during the two minute tracking session. This means that
the laboratory data provided very little information about the
cardiac or eye blink changes that took place during flight.
More importantly, this means that in order to understand the
data collected from ambulatory subjects while they perform
their daily tasks, we must have a database constructed from
these environments.

We also have collected the first evoked brain potentials
recording during actual flight. There are literally hundreds
of laboratory evoked potential papers and the use of evoked
potentials to evaluate pilot workload has been discussed by
many investigators for a number of years. While our main goal
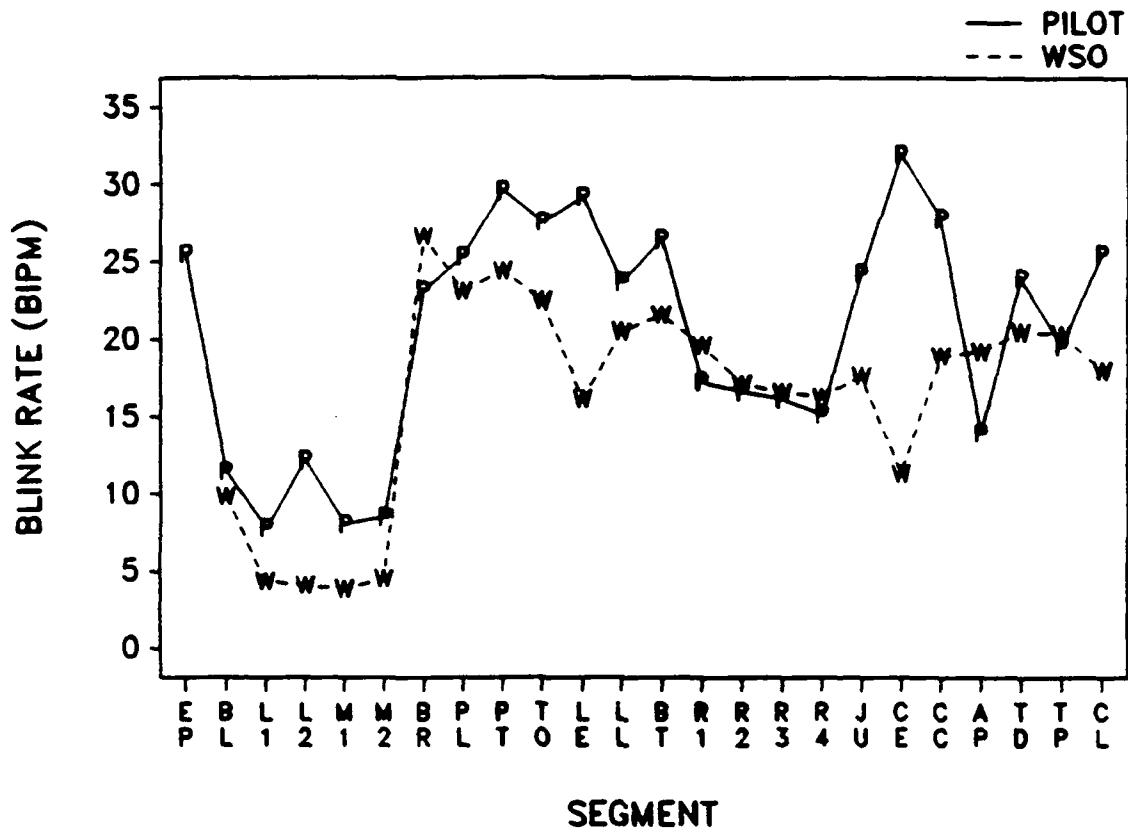
Figure 5. Pilot and WSO blink rates for the F-4 air-to-ground training missions. Note the large suppression of blinks during the ground based, single task tracking segments when compared to the ground-based preflight briefing and flight data. The data are from the same crew members in Figure 4 and the segment legend is also identical.

was to demonstrate that evoked potentials could be recorded from pilots while flying, we were pleased to find that the evoked potentials provided meaningful data on the workload experienced during the two flight segments. We recorded auditory evoked potentials while the pilots were on the ground

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during a resting period and during the tracking task prior to flight to provide ground-based data for comparison with the flight evoked potentials. The flight evoked potentials were collected from the pilots during two cruise segments, one when the pilot was flying the aircraft and one when the WSO was flying the aircraft. The pilots' workload was higher when he was flying the aircraft as was supported by the subjective workload ratings. The evoked potentials from the five segments are shown in Figure 6. These data represent the grand mean averaged evoked potentials from the seven of ten pilots whose data were acceptable. The evoked potentials were recorded between midline scalp parietal and central sites. The mean amplitudes of the positive going component with a latency of about 200 msec (P2) is shown in Figure 7. The amplitude of this component decreased during the highest workload segment, pilot flying, and not during the other flight segment when the pilot was not flying the aircraft. These data demonstrate that with care brain evoked potentials can be recorded during flight and that they produce meaningful data with regarding the pilots' cognitive workload. These data encourage us to continue collecting evoked potentials during flight and to expand to other flight situations (Wilson & Fullenkamp, 1990; Wilson Fullenkamp & Davis, in press, Wilson, in press).

Flight Segment Classification

While most laboratories record only one type of physiological data, heart rate, EEG, or eyeblink, for example,

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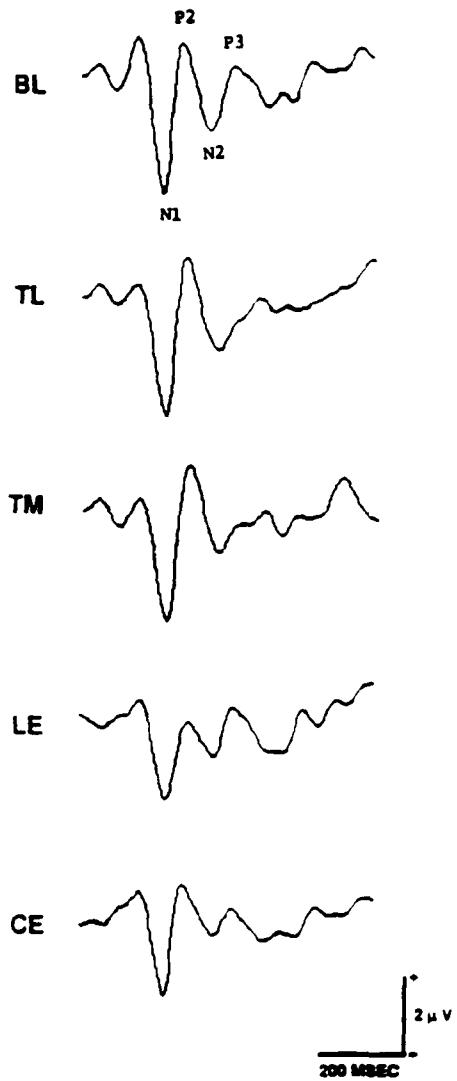
Figure 6. Grand mean evoked potentials from seven pilots in response to auditory tones. The evoked potential components are labeled on the top most average. The evoked potentials were recorded during the BL - baseline, TL - low level tracking, TM - medium level difficulty tracking, LE - low level outbound flight (pilot flying) and CE - cruise inbound (WSO flying).

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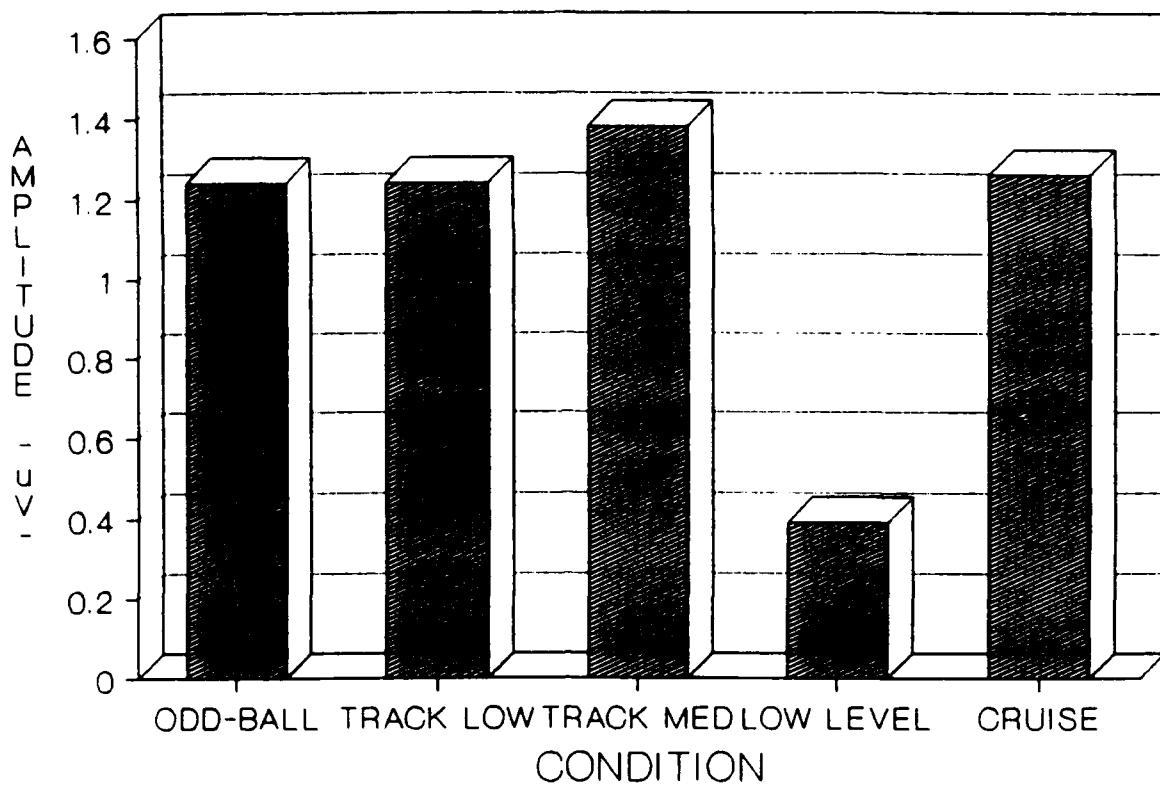
Figure 7. This graph represents the mean amplitude of the P2 component of the evoked responses from each of the five segments. Note that the only significant reduction in P2 amplitude was during the segment in which the pilot was flying the aircraft and not during the segment when the WSO was flying, nor during the tracking task segments.

we routinely collect several types of physiological data (including performance and subjective data). We analyzed these data separately, and then combine them to permit synthesis of the several results. This is illustrated in the F-4 study in which five different physiological signals were collected. We have tested methods of synthesizing these data to be able to gain additional information to that available from any one of

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the separate results. We feel that this approach is valid since flying modern aircraft is not a single task but places demands on many aspects of the human cognitive system. Consequently, no one physiological measure will be adequate to characterize the mental workload of all aspects of flight. Further, the physiological systems of individual pilots respond differently to the workload and stresses of flying, thus by making many measures we are able to accommodate the unique response characteristics of each pilot.

A recent example of this approach was our demonstration of the capability of classifying eight flight segments on the basis of the physiological data for the F-4 pilots and WSOs described above. Seven variables derived from their heart and eyeblink data were submitted to stepwise linear discriminate analysis in order to determine the capability of correctly classifying eight of the flight segments. Using the flight data for both the training and test data sets we were able to correctly classify all eight flight segments (100%) for seven of the pilots, 90% of the time for one pilot and 80% for the other two pilots. The classification success for the nine WSOs with complete data was 100% for seven of them and 90% for the other two. This is a very high rate of success but it must be noted that the same data set was used for training and testing the classifier since we did not have a replication of the mission segments. The jackknife procedure was used to provide a conservative estimate of the goodness of classification and was in the neighborhood of 70% correct for both pilots and WSOs

(Wilson & Fisher, 1991). We plan to collect two sets of data in our next flight study so that we will be able to test the goodness of classification accuracy using a different test set.

These three airborne studies provide us with a data base that is unique in the number of aircraft types used and the roles of the subjects. Single-seat, low-level attack aircraft, two seat fighter-bombers and multicrew bombers were used. Many of the flight segments are similar for all of these aircraft; takeoff, cruise, and landing, for example. From this data base, we can identify similarities and differences across the several missions. This information will help us generate a picture of the general effects of workload and also the effects of specific factors related to mission type and aircraft type. It is unusual that one laboratory has such a diverse data base and the potential for enlarging upon it. We plan to continue our flight studies in order to enlarge our database and increase the number of unique situations. It is necessary to collect inflight data since laboratory data has limited usefulness when one wants to extrapolate to the realm of flight, as was demonstrated in our F-4 project.

C-17 Test and Evaluation

We are currently working with the C-17 Test and Evaluation (T & E) test team in their evaluation of the C-17. They plan to use heart rate and possibly eyeblink measures as part of the operational T & E plan for the C-17. This is the first time that physiological data have been used as an integral part of a

T & E test plan to directly measure crew workload. Cognitive

work overload is a concern with the C-17 since only two crew

members will fly the aircraft rather than the larger crew used

on existing transport aircraft. Since no absolute overload

criteria or "red line" values exist for any workload measure,

our approach is to use values from similar mission events in

current aircraft to provide baselines to compare the new

aircraft. If the physiological responses are not different

from the baseline aircraft values for the same maneuvers, then

the workload in the new aircraft is acceptable. However, if

the physiological data in the test aircraft deviate

significantly from the baseline aircraft, then the workload can

be judged as too high. We are collaborating with the C-17 T &

E team to collect physiological data from their pilots during

proficiency missions in their currently certified C-130 and C-

141 aircraft. Since these are accepted aircraft, we will be

able to compare the physiological responses from their pilots

during the same mission events in the C-17 with those in the

older aircraft. This will enable them to determine if the

workload in the C-17 does or does not exceed that of the older

aircraft during the same mission events, e.g., takeoff, air

drops, etc. An example of the baseline data during a high

workload Low Altiltude Parachute Extraction drop is shown in

Figure 8. The eyeblink record from the pilot show the pattern

of blinks and their durations before, during and after the low

level drop. The inhibition of blinks at the drop show the

responses to the extremely high visual workload when flying
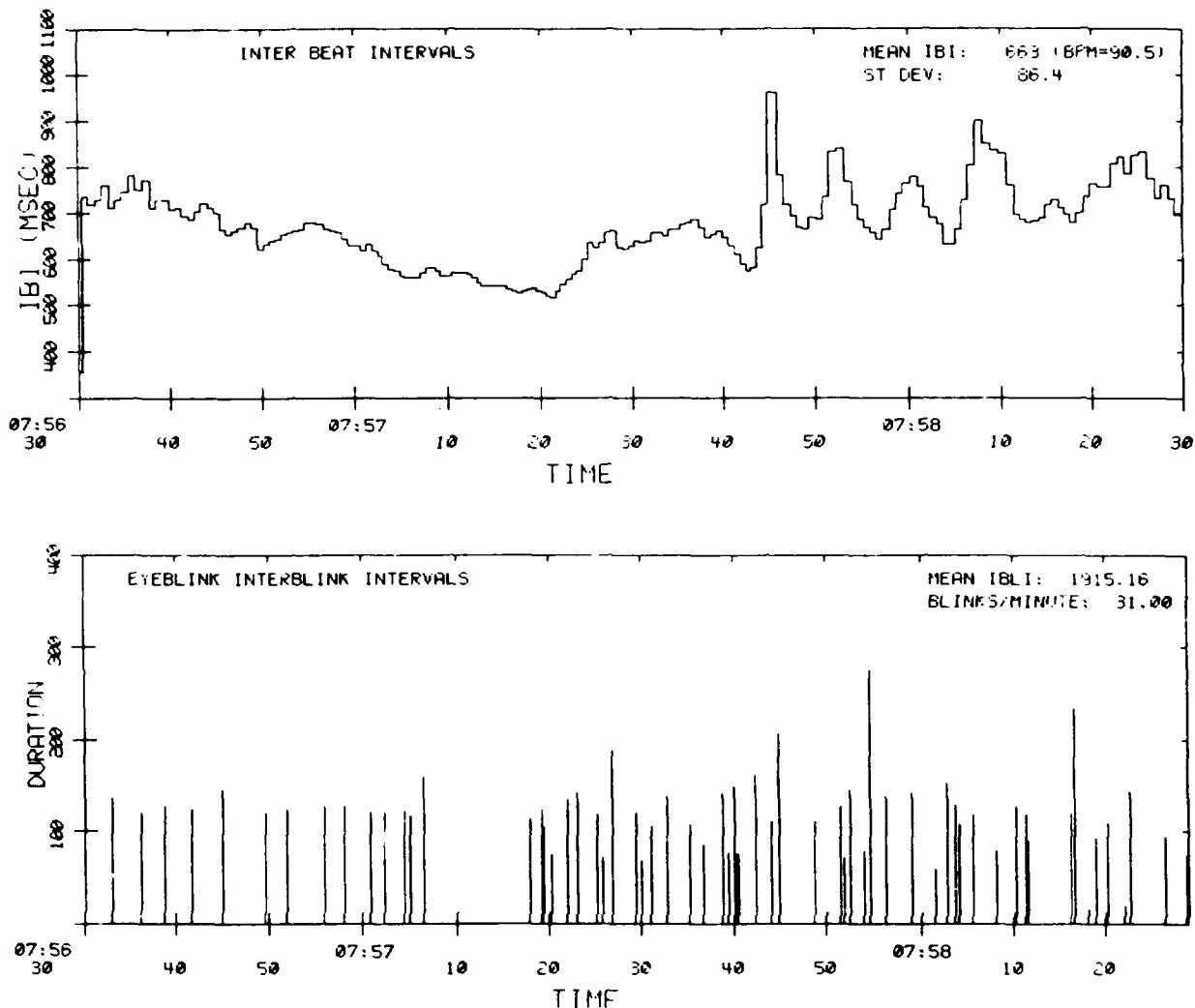
Figure 8. Cardiac and eye blink responses recorded during a C-130 low level cargo drop. The inhibition of blinks and decreased interbeat intervals occurred during the drop and provide measures of the increased workload during this segment. The vertical axes are IBI (interbeat intervals) for the cardiac data and duration of the eye blink closure for the e.e blinks, both in milliseconds. The figure shows the pattern of responses for both measures.

extremely close to the ground and experiencing the radical changes in aircraft flying characteristics as the large load is

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pulled from the aircraft. The heart rate increases during this maneuver as is shown by the decreased interbeat intervals in the top panel of the figure.

Inflight Voice/Time Code Recorder

During the A-7 study, it became obvious to us that we needed a better method to mark and later locate the time of important mission events. The times were necessary so that we could correlate the physiological data with specific mission events. Our first approach of tape recording aircraft radio communication was unsatisfactory; the lack of a continuous time record made it difficult and time consuming to accurately correlate mission events with the time that the event occurred. Consequently, we developed a device that simultaneously records aircraft communications and a time code. A small, personal, commercially available stereo audio recorder and playback unit is now used in our flight studies. The aircraft communications are recorded on one channel and a time code from a microprocessor is recorded on the other channel. The unit is small and can be worn by a crew member or placed in the aircraft. After the mission, the taped signals are played back and a LCD display shows the time as the audio record is heard so that the time of important mission events can be determined to an accuracy of one second. Several other research groups with similar requirements have expressed interest in this device and a patent application has been submitted, by the Air Force, to the U.S. Patent Office (Wilson, Hall & Benadam,

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1991).

Related Efforts

In order to expand our range of environments for data collection, we have installed a Neuropsychological Workload Test Battery at the ASD/ENECH simulator facility. We have trained their personnel on the use of the system and have collaborated on one study evaluating a new display. The results showed that eyeblinks were sensitive to the workload differences between displays when performance, subjective or heart rate data were not (Wilson, Hughes & Hassoun, 1990). This cooperative effort afforded us access to a simulator facility and will permit us to explore the application of our measures in this environment. Additionally, it will provide exposure of psychophysiological methods to a wider audience since ASD/ENECH works directly with several SPOs.

In order to enhance information exchange between researchers who collect psychophysiological data in "real world" environments and to increase our own understanding, funding was obtained from the European Community to hold a workshop entitled "Psychophysiological Measures in Transport Operations." The meeting was held in Cologne, Germany, November, 1990. Nineteen scientists presented their work on ambulatory recording during different types of transport operations. These included airplanes, buses, cars, trucks and locomotives. Most of the attendees were from Europe and three were from the United States. A wide range of problem areas, data collection and analysis methods were represented.

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Selected papers from the workshop will appear in a special issue of the journal Ergonomics (Wilson, in press).

LABORATORY

Our laboratory efforts are aimed at improving our understanding of cognitive workload and subject state and also to develop and test new procedures to aid in the measurement of operator workload and state. These efforts include developing techniques that will permit us to better understand human information processing and to evaluate available procedures for possible inclusion in our test battery.

Heart Rate Variability

An example of our evaluation of existing procedures are the comparative studies that we have recently undertaken to evaluate the value of heart rate variability (HRV). HRV refers to the variation in the interval between heart beats, see the beginning and ending portions of the bottom of Figure 2 for an example. This variability between beats is thought to decrease under conditions of higher cognitive activity and to increase as the cognitive activity decreases. There is a large literature based on laboratory results of heart rate variability as a measure of higher nervous system involvement in various tasks. There are numerous methods used to calculate HRV; in 1973 Opmeer found 26 different methods (Opmeer, 1973). Some of these methods are commercially available. We have tested four of these methods using existing laboratory and flight data. Our first question was: does HRV tell us anything

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more than we can learn from heart rate alone? The second question was: if HRV is a valuable tool, which of the methods of calculation is best, or is one better in certain situations while others have advantages in other situations? We used heart rate data collected in laboratory experiments, data from simulators, and data from flight studies. This wide range of data permitted us to make definitive statements about the utility of HRV and about which of the various methods is best in a given situation. To utilize the expertise available in this area, we held a Heart Rate/Respiration Workshop in Dayton during the Summer of 1989 in which seven experts from Europe and the United States participated. The goal was to have them address the issue of the proper use of these measures in Air Force and other applied environments. The proceedings of this workshop will appear as a special issue of the journal Biological Psychology (Wilson, in press). We learned a great deal from the workshop concerning the collection, reduction and analysis of heart rate data and by publishing the papers this information will be available to others.

The results of our testing the utility of HRV are that it does not seem to add appreciably to conclusions drawn on the basis of simple measures of heart rate. While heart rate data displayed graded differences between the several levels of workload in flight, HRV measures seem to be dichotomous. For example, the HRV shown in Figure 9 contrasts with the heart rate data from the same flight segments shown in Figure 4. While the heart rate data show several levels corresponding to

the workload levels of the ground and flight segments, the HRV data show only two or possibly three levels. Also, from the variability data, it is not clear why the tracking task is associated with the same degree of reduction of HRV as the bombing range segments during flight. It appears that the variability measure is indicative of the presence of cognitive activity, but does not give information about the degree of cognitive involvement. This limits the application of HRV in our environment since we require graded measures of mental effort and not just an indicator of its presence or absence (Wilson, 1991).

Further, in a study explained below, we assessed the effects of learning a task and adaptation to the laboratory while subjects performed a mathematics task. We found that heart rate changes were associated with learning the task, adaptation to the laboratory, and the difficulty levels of the task, while the HRV measures were sensitive only to the adaptation to the laboratory and not task difficulty (Wilson & McCloskey, 1986).

With regard to the issue of which of the several measures of heart rate variability to use, we have concluded that those we tested seem to be equivalent to one another. Only small differences were found between the results of these methods that were inconsequential. This has been borne out by a recent article which also compared several measures on laboratory data (Grossman & Wientjes, 1991). However, the choice of method may
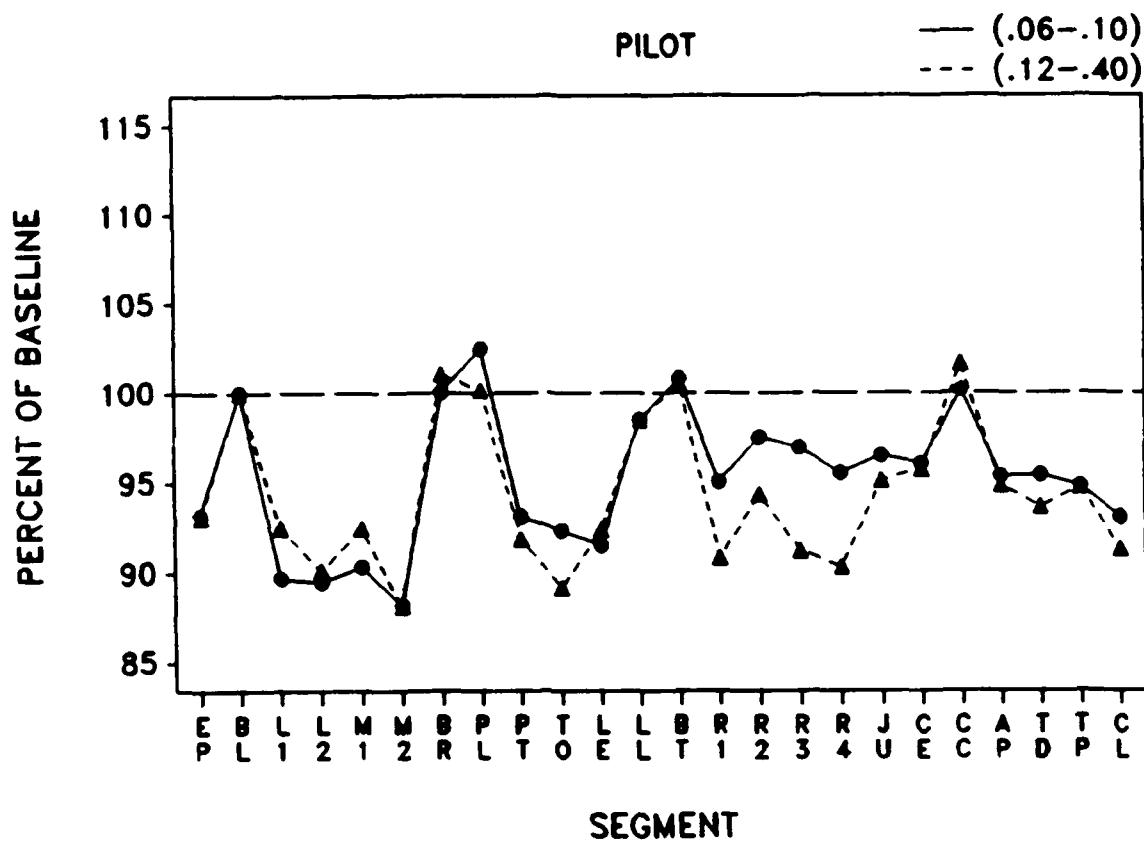
Figure 9. Mean heart rate variability for the 10 pilots during F-4 air-to-ground training missions. The data are plotted relative to the ground-based resting segment. Note that only two or possibly three levels of HRV are shown in contrast to the more varied response levels of the heart rate data shown in Figure 4. The segment legend is explained in Figure 4. Two bands of HRV are represented, 0.06 - 0.10 Hz, i.e., the blood pressure or Traube-Hering-Mayer wave, and 0.12 - 0.40 Hz, i.e., the respiration band. The responses in these two bands are statistically equivalent.

be governed by practical considerations such as the length of the available data record. The spectral analysis techniques,

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by nature, require a minimum of three to five minutes of data to sufficiently resolve the lowest frequency bands. In many situations, especially in the "real world," only shorter epochs of data are available. The methods that use filtering techniques have the advantage in these situations since they are valid with shorter segments of data. However, if one is interested in the relationship between cardiac and respiratory activity, the spectral and direct measurement techniques have the advantage since they permit the direct comparison of the cardiac and respiration activity.

Learning and Adaptation Effects on Heart Rate

With regard to cardiac measures of workload in the laboratory, one line of current inquiry arose from our inability to produce heart rate changes in our subjects as a result of cognitive task difficulty manipulations (McCloskey, 1987; Wilson, et al., 1986; Yolton, et. al., 1987). We concluded that there were significant differences between our experimental methodology and that of the studies reported in the literature. While the subjects in the studies reported in the literature were usually naive to the task used, our subjects were practiced to a performance criteria prior to physiological data collection. In gaining experience with the task, our subjects also became adapted to the laboratory environment while subjects from the other studies were in the laboratory only on the day of testing. This led us to perform a study with naive subjects from whom we recorded heart rate

and respiration as they practiced the task to criterion performance levels. As we had predicted, there were significant task difficulty effects early in the training, prior to achieving criteria, that went away with practice, see Figure 10 (Wilson & McCloskey, 1986). These results are very important since they show a context effect which severely restricts the application of previous laboratory results. It suggests that typical laboratory data may have limited utility in predicting "real world" effects since operators are typically highly overtrained and quite adapted to their work environment. In addition to these findings, we have found that flight data is quite different from laboratory data in terms of the magnitude of change. The range of heart rates reported in laboratory studies may be 6 to 10 bpm (approximately 10%) and exhibit statistical significance. As discussed above, we routinely find up to 40% to 50% increases in heart rates during normal flights! A new body of data will be necessary from the "real world" so that this type of data can be properly interpreted.

We have also begun collecting respiration data in addition to heart rate. One component of the HRV is driven by respiration activity, 0.12 - 0.40 Hz. There is reason to believe that the respiration signal itself should be analyzed since it drives this component of the HRV and may be a better measure of workload effects. We have collected respiration data in both laboratory and flight studies. Dr Richard Backs, Wright State University, performed a study in our laboratory
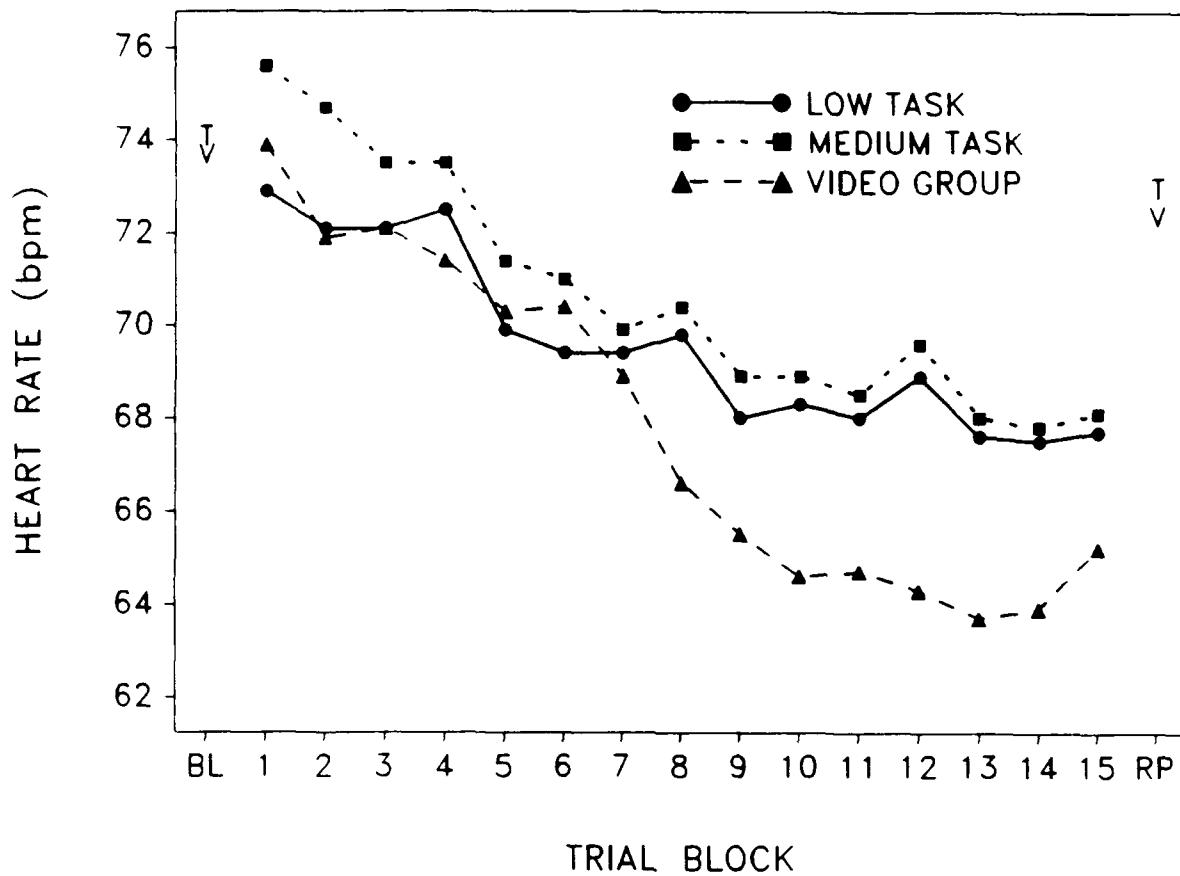
*Figure 10. Heart rate measures from the two groups of
subjects during 15 three-minute trials of learning a
mathematics task having two difficulty levels (task group) or
watching a video tape (video group). The heart rates from the
two groups decrease together over trials until trial block 8
when the video group heart rates decrease more rapidly. Within
the task group only the first four trial blocks exhibited
significant differences between the low and medium difficulty
levels of the task.*

and is continuing this research in his laboratory with funding
from the Air Force. He is investigating the relationship
between increases in cognitive and physical workload on cardiac
and respiratory activity. Both of these variables are

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influenced by workload manipulations and the goal of his work
is to understand these relationships using single and dual task
paradigms.

Investigation of Brain Activity

Since the brain is the organ responsible for cognition,
direct measurement of the activity of this organ during
cognition should lead us to a better understanding of both
brain function and cognition. The electrical and magnetic
activity of the intact human brain can be studied in several
ways. One is to monitor the on-going activity by performing
spectral analysis on the EEG and searching for changes in the
frequency composition of these signals. Another procedure is
to measure the small amplitude changes in brain activity that
are evoked by environmental stimuli. Since these small
amplitude potentials are overshadowed by the on-going brain
activity, ensemble averaging is used to extract the signal from
the background EEG or noise.

Probe Evoked Potentials

Using evoked potential methods on brain wave data we have
performed several studies using the so-called "probe" evoked
potential technique. The "probe" stimuli are superimposed upon
an ongoing task and the brain response to these probe stimuli
is used as a measure of involvement in the primary task. The
probe stimuli are non-intrusive in that no behavioral response
or attention to the probes is required by the subject. The
assumption is that the level of processing of the task-

irrelevant probe depends upon the cognitive resources remaining after processing of the primary task. If the primary task is more demanding upon cognitive resources, then the brain response to the probe will be diminished. Our results to date have shown that the probe must be presented during the actual time of active involvement with the primary task. That is, if a task is used which has discrete trials in which stimuli are presented periodically and the probe stimuli are randomly presented, small changes, if any, in the probe evoked response will be found. This occurs since there is no competition for cognitive resources when the probe stimuli occur during times when the subject is not processing task information but is waiting for the next stimulus. If the occurrence of the probe stimuli is synchronized to the occurrence of the task stimuli, e.g., 250 milliseconds following task stimulus onset, then the evoked potentials to the probe stimuli will be reduced in amplitude (Wilson & McCloskey, 1988). Figure 11 shows the amplitude changes found in probe evoked potentials. Prior to our work this point was not clear.

The F-4 evoked potentials, described above, were recorded using the probe paradigm in which tones were presented while the pilots were engaged in the tracking task, flying the aircraft or while the WSO flew the aircraft. The probe evoked potential P2 component amplitudes were reduced during the pilot flying segment and demonstrates that if continuous processing tasks are used, then the probe technique can be used to monitor operator workload. Theoretically, the probe paradigm could be
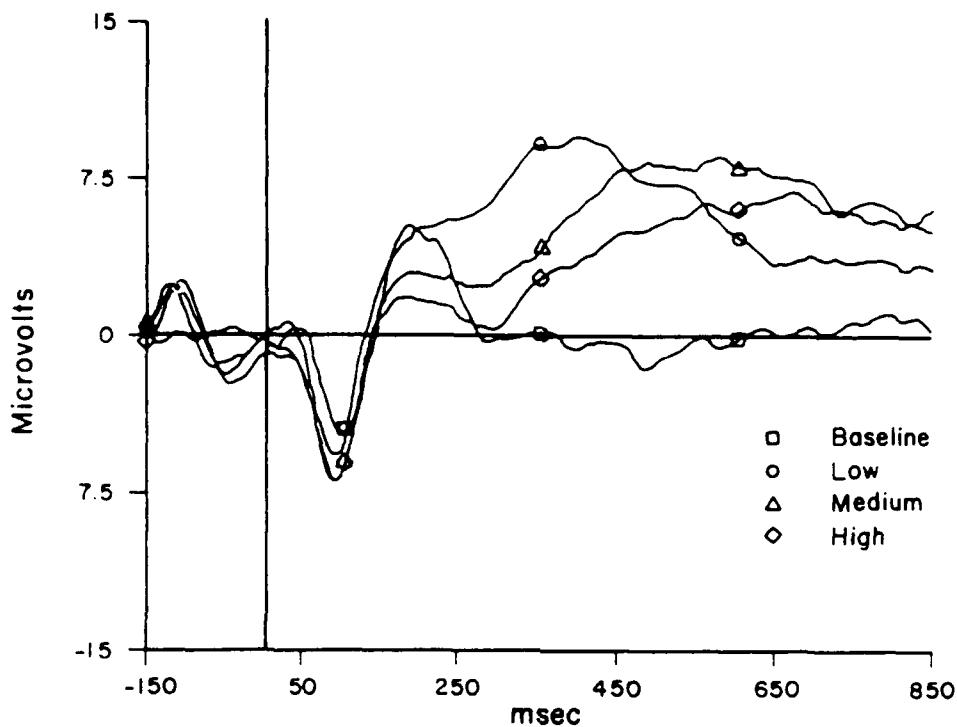
Figure 11. Evoked potentials to probe stimuli that were presented 250 msec after the onset of the primary task stimuli in a mathematics task. The baseline evoked potential was collected during a probe-only condition. The reduction of the amplitude of the early components can be seen in the figure.

used to define the temporal limits of cognitive processing of the primary task. We plan to continue to use this method in "real life" situations to test its utility in other situations.

Task Stimuli Evoked Potentials

Another approach to using evoked brain responses to measure cognitive activity is to record the evoked potentials to the task stimuli. The probe stimuli are superimposed on an ongoing task, in this case the evoking stimuli are the actual

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task stimuli that the subjects must process. We have used this approach to investigate how the brain processes information in situations with different difficulty levels. A number of cognitive tasks have been used, most of them from the Criterion Task Set (CTS) developed by Shingledecker in our Branch (1984). A consistent result from these studies is that the late evoked potential components are reduced in amplitude as the task difficulty increases. An example of this is seen in Figure 12 which shows evoked potentials from a midline parietal electrode (Pz) from two levels of difficulty of a linguistic task. The literature on this topic is small and contradictory. We are not certain, yet, why we find amplitude reductions in the task stimuli evoked potentials but we have several hypotheses that we plan to test. For example, it could be that the increased task difficulty results in more distributed cortical activity that results in a reduction at any one electrode site. Another explanation is that the latencies of the individual brain responses to the stimuli are more variable, as is sometimes found in performance measures as increased variance in the reaction times. This would tend to reduce the component amplitudes as a result of the averaging process. We plan to test these hypotheses in future experiments.

Electrical Brain Mapping

Typically, evoked potential studies use a small number of scalp electrodes, usually three to six. These data provide a time history of the electrical potential changes following stimulus presentation while the brain is processing the
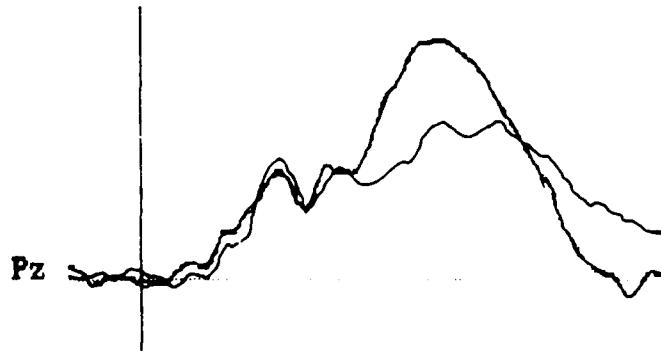
Figure 12. Averaged evoked potentials from the parietal midline electrode (Pz) recorded during the performance of a linguistic task having two levels of difficulty. Note the reduced amplitude of the large, late positive component in the more difficult level of the task. The averages represent 1024 msec of activity and the vertical line is at stimulus onset.

information. Current software and hardware technology make it possible to simultaneously record from many more scalp sites. Commercially available systems permit the recording of 20 to 32 channels and some laboratories have systems with up to 128 channels. These methods add the spatial dimension to the time dimension formerly available. With these systems, one can see the potential changes over the head as they change in time enabling exploration of the functional neuroanatomy with brain topographical techniques. That is, we are able to watch the time history and see where on the surface of the scalp the brain activity is taking place as information is being processed. We have used our 19-channel EEG brain mapping

system in several evoked potential and on-going EEG studies to better understand how the brain processes information in different types of tasks and under different levels of difficulty or workload.

The advantage of using electrical brain mapping was demonstrated in one study in which the subjects performed a spatial rotation task with three levels of difficulty. It was possible to follow the flow of information processing over the head by following the spatial location of the evoked potential components over time. Reduction in electrical activity was again associated with increased task difficulty. The utility of the brain mapping procedure was shown when activity in the right hemisphere central cortex was located that would not have been seen from the typical midline electrode sites (see Figure 13) (Wilson, Swain & Davis, 1988).

In another study, three different tasks, each having two levels of difficulty, were performed by the subjects while we recorded 19 channels of EEG. This permitted us to determine the effects of different levels of task difficulty in each of three tasks so that we could determine if the evoked potential changes would be universal across tasks or unique to each task. Further, the topographic data allowed us to follow the flow of information in the brain during each task and evaluate how it differed across tasks. The tasks were a stimulus degradation task, a mathematical processing task, and a linguistic task. The effect of increased task difficulty was associated with reductions in the amplitude of the late evoked potential
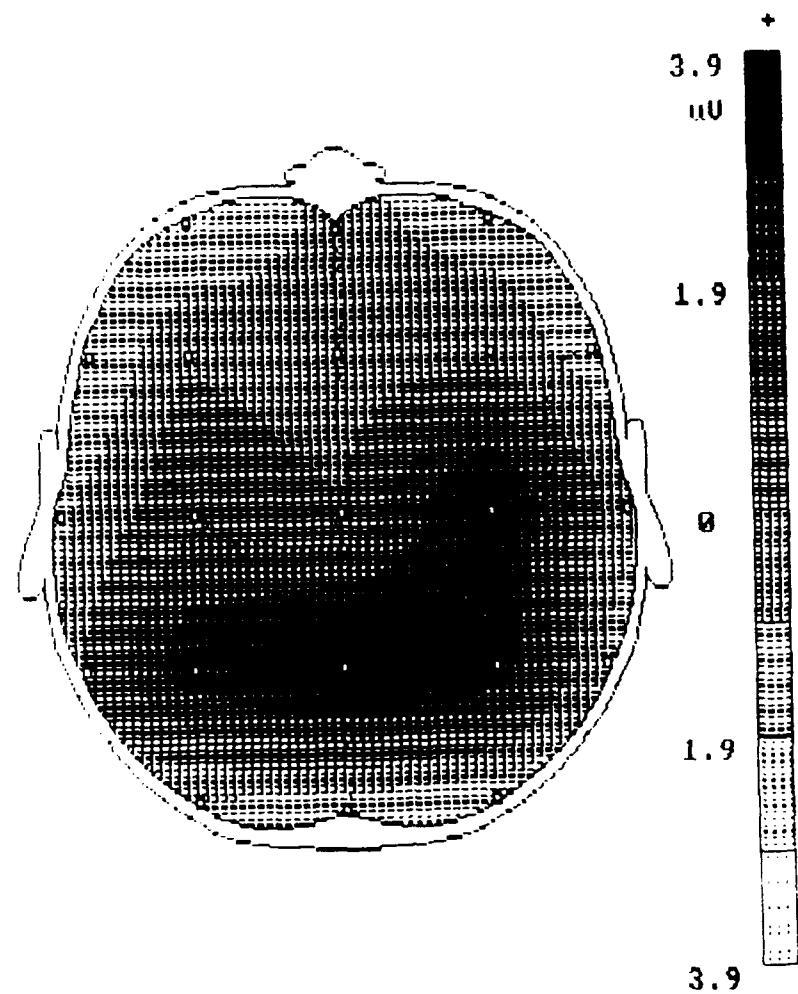
Figure 13. Topographic map of a late positive component
of the evoked potential recorded during the processing of a
spatial orientation task. The maximal positivity is seen in
the right hemisphere central and parietal midline areas. The
right central positivity would have been missed if the
recording sites were restricted to only midline electrodes.

components in all three tasks. The stimulus degradation task,
which manipulated earlier perceptual processing, was also
associated with larger, early components to the degraded

stimuli. Apparently, the degraded stimuli produced increased activity early during the perceptual states of processing, but were associated with decreased amplitudes in the later components associated with evaluation and decision making. The pattern of activity over the head was quite different among the tasks and could be used to characterize each task (Wilson, Palmer, Oliver & Swain, 1991). For example, the brain areas associated with significant differences between evoked potential components due to differences in task difficulty as shown in Figure 14. These data represent the pattern of component differences due to task difficulty for two tasks, stimulus degradation and mathematical processing. These patterns show the differences in the cortical areas activated and in the temporal sequence of their activation. This sort of analysis permits us to begin developing an atlas of functional brain topography. With this atlas, we will be able to determine the type of task being performed from the pattern of cortical area activation. This will permit us to determine similarities and differences in cognitive function between different cognitive tasks. With this information, we will be able to derive a much better understanding of human cognitive brain functioning.

Dr Victoria Nasman and Barbara Palmer have conducted a study n which they utilized electrical brain mapping techniques to investigate the changes in evoked activity while subjects performed a language task with increasing levels of difficulty. The task stimuli were drawn from the same set of four letters
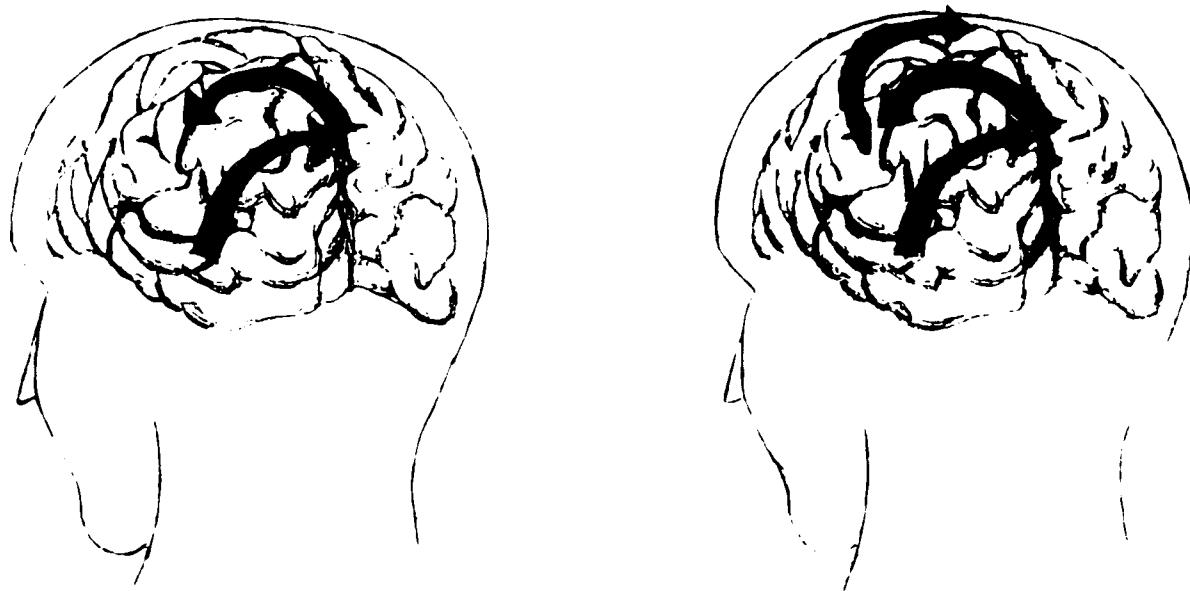
Figure 14.   Patterns of electrical activity that represent the differences between the two levels of task difficulty for two tasks.   The pattern for the stimulus degradation task is on the left and that for the mathematics task is on the right.

for each level of difficulty and the only difference was the subject's task.   In each case, two letters were presented simultaneously.   Subjects were asked to indicate by pressing one of two buttons if the letters were (1) physically identical, (2) same name regardless of case and (3) both vowels or consonants.   The evoked potential amplitudes were smaller for the more difficult levels of this task.   However, the evoked response amplitudes were larger for the match than the not-match categories of the levels.   The evoked potentials associated with a simple reaction time task to the same

stimulus set were notably lacking long latency components. These later components of the evoked response are related to the longer duration cognitive processing in the three levels of the language task (Nasman, Palmer & Wilson, 1991).

The differences in the pattern of evoked electrical activity between visual and auditory discrimination tasks were investigated by Dr Celia Oliver. This study was aimed at using the N2 response of the evoked potential to study discrimination and decision processes in humans. The N2 cortical spatial locus is purportedly modality specific, while the location of the P3 is the same for all modalities. Our goal was to test this hypotheses using brain mapping techniques. The results showed that the location of the early, perceptual, components was determined by the modality of the stimulus, temporal-central for the auditory task and occipital for the visual task. With the progression of time, the location of maximal electrical activity in the evoked potentials moved toward the midline parietal areas where the large amplitude, long latency component, P3, was located for both types of stimuli. The N2 components were located at different sites due to stimulus modality as was predicted. These data show that the source of cognitive brain activity early in the processing sequence is modality-specific but common association cortex (parietal) areas are used late in the sequence. This confirms concepts of the functional anatomy of the brain and gives us more information concerning how the brain processes information in this type of discrimination task.

A different type of question was asked in another brain mapping experiment. The question was: is there electrically recordable activity in temporal and parietal areas of the brain in response to stimuli presented to the visual periphery? This work has implications for the understanding of the secondary visual system. Both animal and human studies show evidence for a second visual system driven by the periphery of the visual field. This is potentially important in the area of display design, for enhancing information processing capabilities, and because of the interactions with the vestibular system, it may provide a tool in the study of the perception of normal body orientation, as well as motion and space sickness. If we can better understand this system, then we may be able to use it as another channel for presenting visual information. This could be especially useful as we place higher loads on the foveal visual system. By understanding the peripheral system, we will be able to utilize its capabilities to our advantage.

Dr Gundel, from the Institute for Aviation Medicine, Cologne, Germany, recently completed a year with us. He investigated the EEG cross-power relationships over the brain as subjects performed several cognitive tasks. The goal of this project was to find the interrelationships between different areas of the brain during active cognitive processing of different tasks using on-going EEG. Spectral analysis was performed on the 19 channels of EEG data while the subjects performed the tasks. The cross-power between all combinations of leads for the traditional EEG frequency bands was
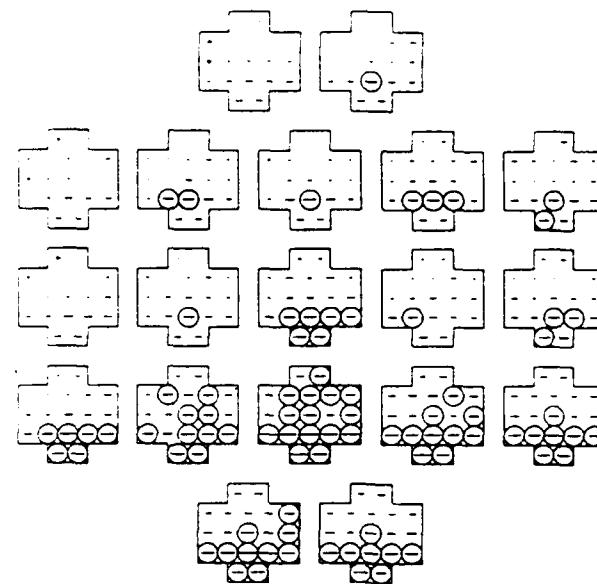
Figure 15. *Cross-power maps for the differences in alpha cross-power between the two levels of difficulty of the visual, probability monitoring task. Each enclosed figure represents the cross-power for that electrode with the other electrodes. The pattern represents the electrode si___ on the head with the nose at the top and the back of the head at the bottom. The length of the negative signs represents the degree of the difference between the cross-power to the two task levels. The circled negative signs indicate that the magnitude of the difference was statistically significant. The preponderance of the differences are over the back of the head.*

calculated. An example of the results for the differences in cross-power between difficulty levels for the probability monitoring task is shown in Figure 15. The minus signs that

are circled designate electrode pairs that showed significantly reduced alpha power in the more difficulty task level, as compared to the less difficulty level, over the parietal and occipital electrode sites. The data showed that the different areas of the brain were active during the different tasks and that the relationships between these cortical areas were also determined by the task being performed (Gundel & Wilson, 1991).

Task Classification Using EEG Data

In another approach, Lt Col Frank Fisher has utilized the on-going EEG to classify the cognitive tasks that subjects were performing. This approach is similar to the one used for classifying flight segments that was described above. However, in this case, we used only EEG data from 19 leads. Spectral analysis was performed on these data and the magnitudes of the 63 integer frequencies between 0 and 63 Hz were submitted to a stepwise linear discriminant analysis. This has not been done before because of the very large data set required, 63 frequency values, 19 leads and 14 task conditions. The EEG data were grouped in several ways, each of the 63 frequency magnitude values, the five standard EEG bands, seven EEG bands (the standard five plus two other frequency bands above the highest standard band) and various groupings of the 63 Hz data, e.g., grouping two adjacent frequencies, three adjacent frequencies up to 12 adjacent frequencies. Each 60 second data set was divided into two smaller sets, training and learning sets, by assigning every other 10 second epoch to one group.

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The highest correct classification of the test data was found when using the seven bands, the five traditional bands plus the two higher bands. The percentage of correctly classified cognitive tasks was 69% for the seven band, 57% for the traditional bands, 41% for the 63 Hz integer bands and the highest percent correct for the adjacent frequency groupings was 42% (Wilson & Fisher, 1991).

Recent advances in EEG analysis technology, partially spurred by advances in MEG, make it possible to estimate the cortical source of particular aspects of the EEG and evoked potentials. These techniques are more precise than mapping surface potential field maps shown earlier in Figure 13, even with the Laplacian correction. Using these techniques, we plan to be able to better determine the cortical sources of activity during the processing of different tasks and to gain understanding of how increased workload in the form of increased task difficulty effects the sources of this activity. We have acquired the software package developed by Dr Michael Scherg which interfaces with our brain mapping system so that we can readily perform the source analysis on the topographic data.

Using Combined Physiological, Performance, and Subjective Measures

We have undertaken studies to explore the relationship between physiological, performance and subjective measures recorded while subjects perform CTS tasks (see Figure 16). The several studies that we conducted show discrepancies between

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the physiological and performance/subjective data. The physiological data often will discriminate between low and medium difficulty levels but not between medium and high. Since the task difficulty levels were selected on the basis of reaction time and subjective estimates of difficulty, it is not surprising that these two measures are highly correlated. The lack of agreement of the physiological data could have at least two explanations. The first is that the physiological measures are not sensitive enough and suffer from a ceiling effect. It is also possible that the performance and subjective differences are not due to increased workload, but merely time. That is, the most difficult level of the tasks involve the same workload levels, but due to the nature of the tasks these activities are performed over a longer period of time producing longer RTs and increased subjective estimates of difficulty. One test of these two possibilities would be a dual task situation in which tasks utilizing the same resources are simultaneously performed. One task would remain constant (secondary task), while the workload of the other task (primary task) would be increased. Linear decrease of performance in all levels of the secondary task would support the insensitivity hypothesis while a leveling off of performance decrement to the secondary task between medium and high difficulty levels of the primary task would support the physiological measures.
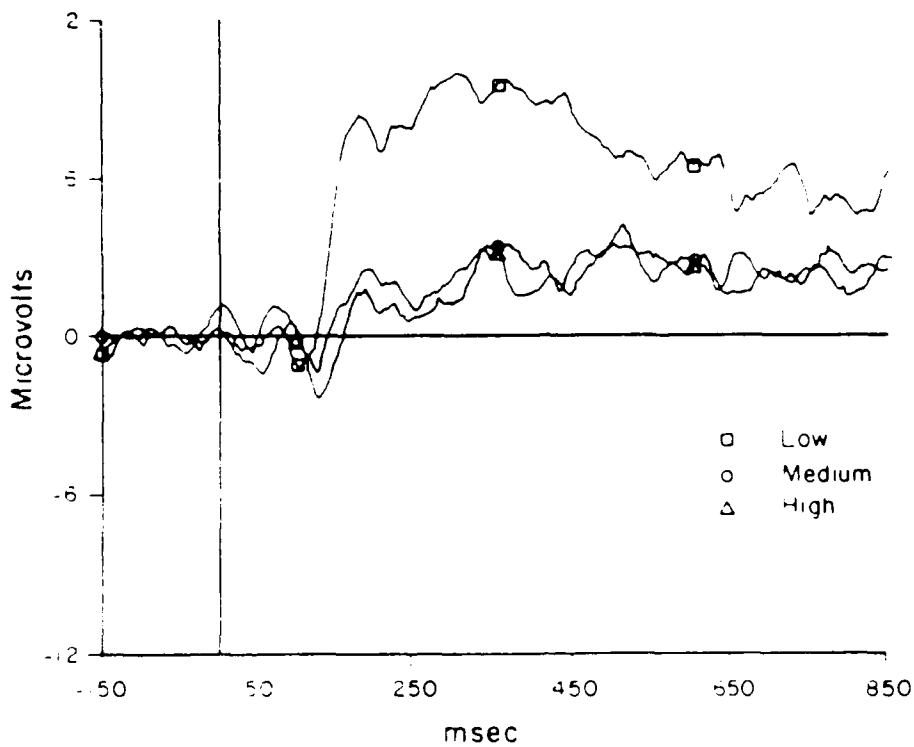
*Figure 16.   Task stimuli evoked potentials during a
mathematics processing task having three levels of difficulty.
Note the decrease in amplitude during the medium and high
difficulty levels compared to the low level.*

MAGNETOENCEPHALOGRAPHY

The magnetoencephalograph (MEG) detects the small magnetic
fluctuations associated with brain activity. This new
technology is being applied to the study of brain functioning
in several areas. Our MEG efforts are aimed at utilizing the
spatial localizing capabilities of the MEG to better understand
how the brain processes information. This device permits us to
examine the magnetic activity from a smaller area of brain
tissue than is possible with standard electrical recording

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techniques. This spatial resolution not only allows us to better estimate the source of brain activity but it also eliminates some of the "brain noise" that is seen in electrical recordings. This can be seen in Figure 17 which represents simultaneous recordings of MEG and EEG evoked responses to the same stimuli with increasing cognitive demands. The magnetic and electrical evoked responses are essentially identical until the cognitive task requires higher level decisions then added components are seen in the electrical recordings but not in the MEG records. This is probably the result of the source of activity of the later components being farther away from the MEG sensor. Due to the greater spatial sensitivity of the MEG, the late component is not detected by the MEG, while the less spatially sensitive EEG detects both.

MEG Evoked Responses to Color

We have shown that the brain processes color information in an area of the occipital lobe that is anterior to the primary projection areas. Further, for the first time, it was possible to draw parallels with data from monkeys showing separate color processing areas that have been demonstrated to be crucial for the perception of color, not just its reception. Thus, we are also able to provide additional support to a new theory of vision based on animal data (Wilson, Peio and Menu, 1985).

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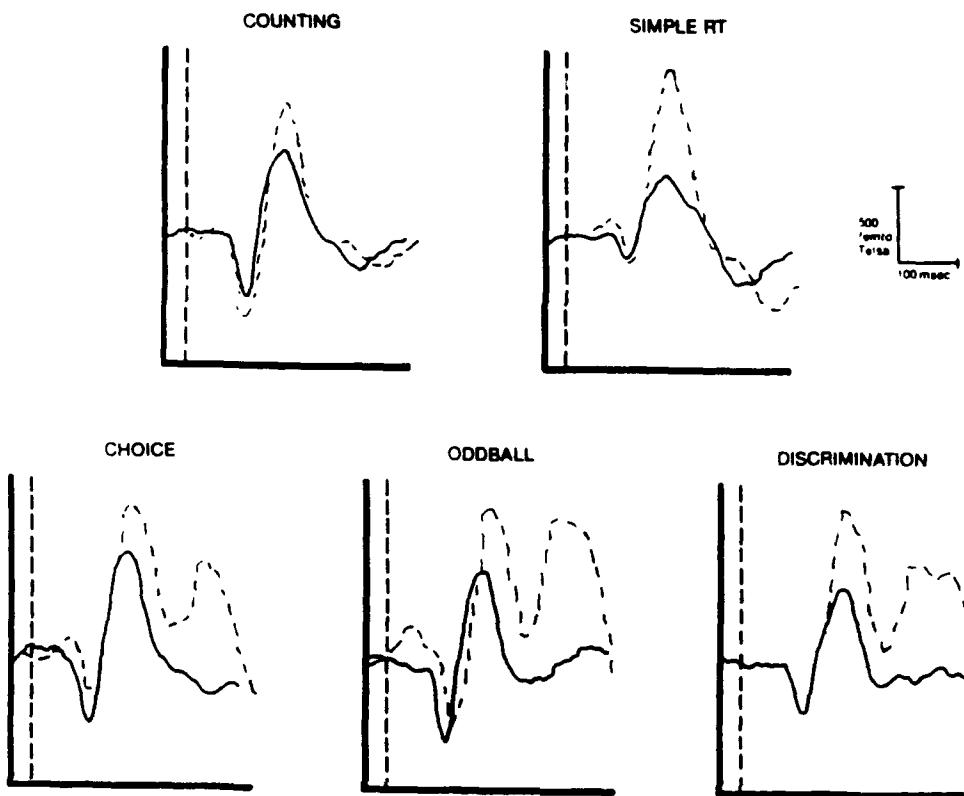
Figure 17. Simultaneously recorded magnetic evoked fields (solid line) and electrical evoked potentials (dashed line) to the same auditory tones while requiring five different types of cognitive activity, from the subject. Due to the differential sensitivity of the magnetic activity, the late positive components associated with increased levels of cognitive activity were not seen in the magnetic responses.
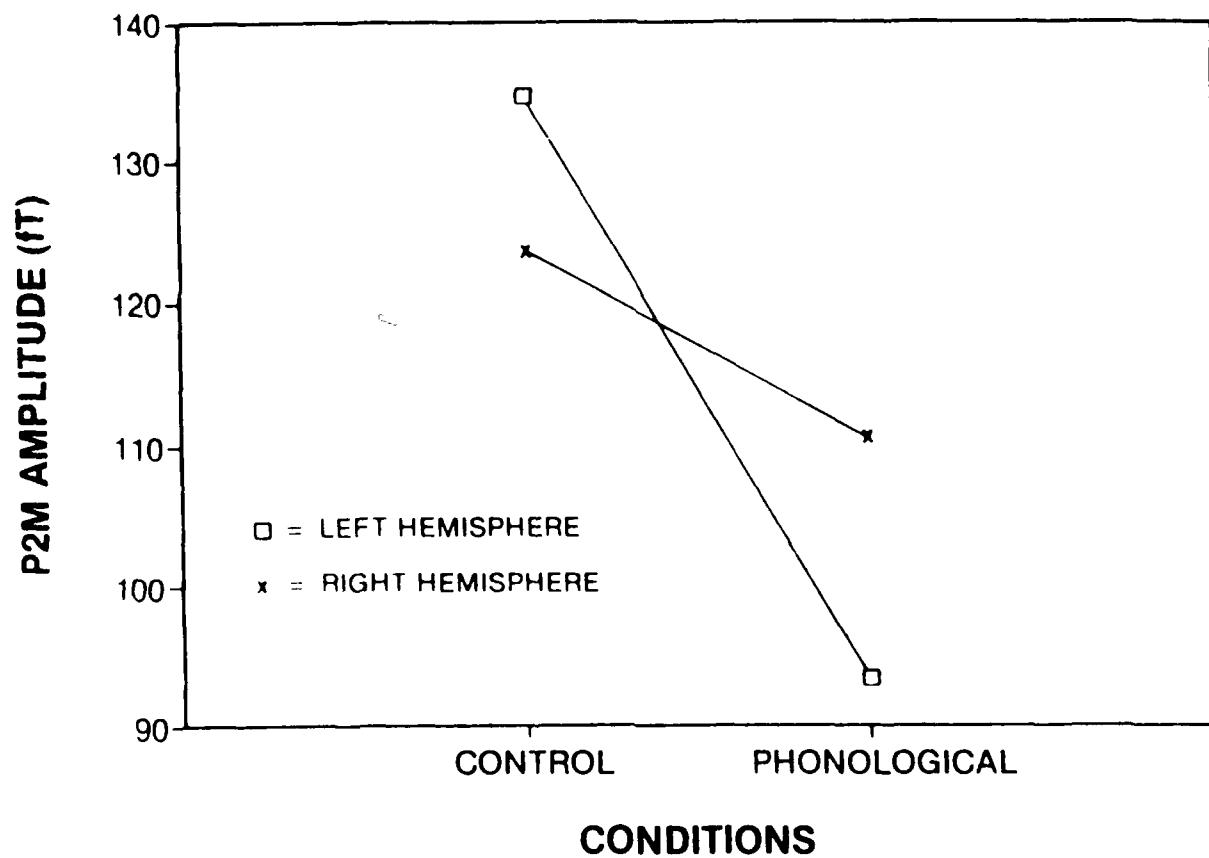
Figure 18. Amplitudes of the magnetic P2M component of the auditory probe evoked responses while subjects listened to only the probe stimuli (control) or performed a language task (phonological). There was a greater reduction in the amplitude of this component in the left, language, hemisphere during the performance of the language task than in the right hemisphere.

MEG Probe Evoked Response Studies

We have used the probe method described above for the EEG studies with the MEG. Our work with probe evoked magnetic

fields has shown several things. The first study, with auditory probes presented during a language task, confirmed that the differential hemisphere reduction in the amplitude of the probe response was indeed occurring in the left (language) hemisphere. As predicted, the evoked fields to the probe stimuli decreased in amplitude more over the left, language, hemisphere compared to the changes in the right hemisphere (see Figure 18) (Papanicoulaou, et al, 1988).

In our second MEG probe study, we found that interpreting visual MEG responses was not as straightforward as it had been for the auditory data. In the visual study, checkerboard probe flashes were superimposed upon the stimuli of a spatial rotation task. Magnetic and electrical evoked responses to the probe flashes were simultaneously recorded from over left and right occipital areas of the head. While the electrical responses demonstrated the expected lateral asymmetrical reductions to the probe in the right hemisphere, the MEG responses did not show this asymmetrical reduction (see Figure 19). The implication is that the less spatially discriminable electrical recordings were a mixture of occipital and parietal cortex responses while the MEG was only reflecting occipital cortex activity. The reduction in electrical response, both ours and those reported in the literature, may be due to reduced resource availability in the parietal area which is primarily responsible for information processing in the spatial rotation task.

A)

B)
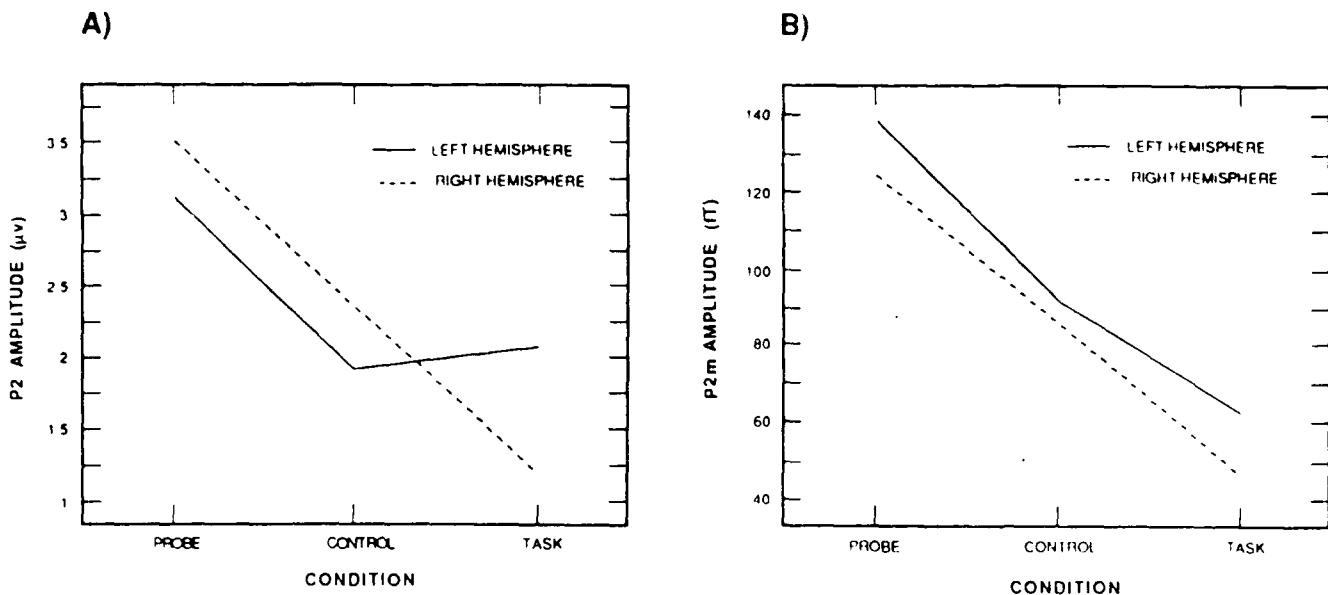
Figure 19. (A) Mean amplitudes for the electrical P2 component and (B) the magnetic P2M component in response to visual probe stimuli while performing a spatial rotation task. The amplitudes showed reductions from the probe only-condition (probe) to the counting of the probe stimuli while the rotation stimuli were present (control) to the actual performance of the spatial rotation task (task). The electrical responses showed a differential response to the task condition in that the right hemisphere did not show further reduction from control to task conditions as did the right hemisphere responses. The MEG showed reduction in both hemispheres to the task condition.

Dr Miyamoto confirmed the presence of anterior MEG responses by locating magnetic sources to visual probe stimuli in the parietal area (Miyamoto & Wilson, 1991). Using this information, we have now repeated the original study while recording MEG and EEG evoked responses from both the occipital

and parietal areas. Our prediction that there would be a greater amplitude reduction in the MEG responses to the probe stimuli in the right hemisphere parietal area than in the left was confirmed. We could thereby locate the active brain site for performing the rotation task in the spatially-dominant right parietal cortex using the MEG (Oliver & Wilson, 1991).

Stimulus Modality Interactions

We are also exploring the interaction of visual and auditory stimuli. To date, we have found that auditory stimuli which occur simultaneously with or precede visual stimuli cause a reduction in the magnetic response to the visual stimuli as recorded from the visual cortex. This occurs even though there is no recordable response to the auditory stimuli from the visual cortex. The mechanism for this interference is not clear. We are planning future studies to determine the locus and nature of this interference. The application of this would be in the area of bisensory information delivery to crew members and how to either take advantage of it or to reduce any negative effects (Busch, et al, 1989).

Related MEG Work

Captain DeRego has developed models of source activity involving multiple dipoles. These models are very useful as we move from the simple, and inadequate, single dipole model towards the more realistic situation in which several sources are simultaneously active. Capt DeRego has also developed the hardware and software for a system that measures each subject's

head and then locates the source of MEG activity using spherical coordinates. This device has significantly improved our measurement capabilities (DeRego & Badeau, 1989).

Through the mechanism of a Small Business Innovative Research (SBIR) contract monitored by Maj Badeau, we were able to simultaneously collect 37 channels of MEG data using the new system available at BTI, Inc. at San Diego, CA. To compare the 37-channel MEG responses to 19-channel EEG responses we provided four subjects who could travel to San Diego and also participate in electrical evoked response collection in our laboratory. We used a simple approach in which two tones, 600 Hz and 1000 Hz, were randomly presented to the subjects. The stimuli were the same in all conditions, only the cognitive processing was changed in order to examine the effects of increased processing on the evoked responses. The tasks were (1) count each tone, (2) simple reaction time to each tone, (3) a choice reaction time task where the subjects pressed one button to the 600 Hz tone and another button to the 1000 Hz tone, (4) a memory task where the subjects pressed one button if a stimulus repeated itself on the preceding trial or press another button if the stimulus was not a repeat. We have collected, but not fully analyzed, the MEG data and have found evidence of a longer latency, slower component as the processing is increased. We will repeat the study with the 19-channel brain mapping system with the same subjects and examine the data for similarities and differences.

NEW ANALYSIS TECHNIQUES

The measurement techniques currently used in human electrophysiology have some limitations in operational environments and thereby are also limiting the areas that we can explore. We need to explore alternatives to the evoked potential and standard EEG analysis techniques that are currently used. They are useful, but impose restrictions upon our thinking and theories. The ongoing EEG is considered by most evoked potential researchers and theoreticians as noise. It is seen as being in the way since it hides the "true" signal from us. As a result many procedures are used to eliminate this "noise." However, some researchers think this is akin to throwing the baby out with the bath water. The currently used evoked potential techniques do provide information and probably can be developed further. These procedures are especially restrictive in the area of operational environments where we do not have much, if any control, over the situations that we must measure and therefore it is difficult to use evoked response techniques. For example, probe stimuli may not be presented at the correct time, it is difficult to synchronize to task stimuli and not enough stimuli may be present to permit response averaging. We are examining several new developments to see how useful they can be to us. Specifically, nonlinear analysis, neural networks, and alpha suppression.

Nonlinear Analysis of EEG Data

Major Albert Badeau has been using nonlinear analysis

techniques to determine the correlation dimension of ongoing EEG data and its relationship to subject state. The goal is to see if this technique can give us better metrics of operator state by using on going EEG. Correlation dimensions were estimated to quantify the change in EEG signal dynamics as subjects performed increasingly difficult tasks. EEG was recorded during eyes open resting, eyes closed resting, and two difficulty levels of a visual probability monitoring task. The EEG signal was embedded into higher dimensional structures, and two dimensional projections were plotted as phase portraits, see Figure 20. The results indicated qualitative differences across conditions. Correlation dimension estimates increased for both task conditions relative to the no task conditions. This technique seems promising and we plan to continue to explore the limits of EEG data using this and other procedures.

Neural Networks

We have performed two projects using neural networks to classify subject cognitive task on the basis of evoked potential and EEG data. Working with Lt Col Morton, we used neural networks to classify single evoked potential trials in data collected using the odd-ball paradigm. The probability of the frequent and rare trials were 70% and 30%, respectively.
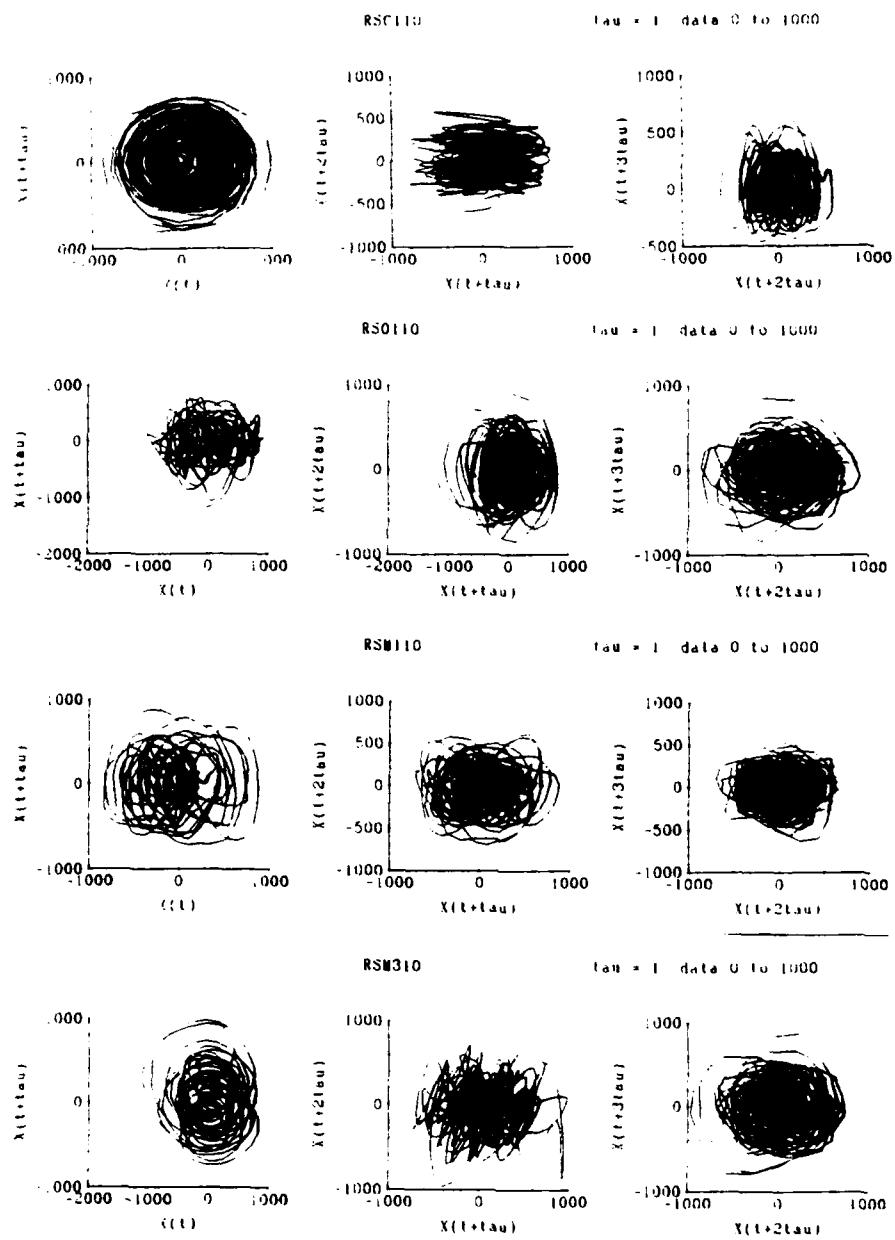
*Figure 20.* Phase plots of EEG recorded during four conditions. The first condition, top row, was eyes closed resting, the second condition, second row, was eyes open resting condition. The third condition was low difficulty level visual monitoring task and the fourth condition was during a more difficult level of the monitoring task. Each column represents 2-D projection of an additional dimension.

These data were divided into two sets, a learning or trianing set consisting of 363 training trials and 100 test trials. The neural network was trained using the learning set of trials and the test set trials were classified using the trained network. Several configurations of the net were used to achieve optimum performance. In addition to the neural net, the same data sets were submitted to stepwise linear discriminant analysis for classification. The percentage correct was essentially identical for the two techniques, 85% for the neural net and 84% for the discriminate analysis. The neural net results are encouraging since it was able to perform as well as the more traditional statistical technique.

Captain Cretchen Lizza conducted a study, as part of her master's thesis, in which she used a neural network to process EEG data which were collected while subjects were engaged in several tasks varying from eyes closed resting to performing two difficulty levels of two different cognitive tasks. She used segments of on going EEG data that were not pre processed and again was able to demonstrate that the neural net could perform as good as or slightly better than discriminant analysis. Much of her efforts were spent finding the optimum parameters for the neural net. This was a very time-consuming task and she had to stop before exhausting all possibilities. More effort should be spent learning about the neural nets so that they can be optimized for classifying EEG data. Future efforts should also explore methods of preprocessing the EEG data prior to submission to the neural net to enhance the

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results. We hope that with further investigation this technique will provide a method of on-line monitoring of EEG data that is a reliable, sensitive method of classifying subject state.

Alpha Suppression

Alpha rhythm block or suppression was one of the first EEG phenomena reported by Berger in the first reports of human EEG. Activity in the alpha band of the EEG, 8 - 13 Hz, is prominent over the back of the head during resting states, especially if the eyes are closed. Opening the eyes or performing mental activity causes the alpha activity to be reduced or eliminated which is commonly called alpha block. Alpha activity is receiving renewed interest by several workers in the area of applied psychophysiology. One of the approaches is to examine the levels of alpha activity following discrete stimuli requiring cognitive activity. Kaufman and co-workers have reported that the blocking of MEG alpha is related to the nature of the cognitive activity. That is, if the task is visual, the blocking occurs in areas of visual association cortex; further, the length of the blocking is proportional to the length of the required processing time as measured by reaction times (Kaufman, et al, 1990). Pfurtscheller and his colleagues have performed similar experiments using electrical recordings of brain activity and have labeled these responses event related desynchronization (Pfurtscheller, 1989).

We plan to utilize these techniques with EEG data to determine how much they can tell us about the brain's response

to task difficulty in laboratory tasks. If they are successful in measuring differences in task difficulty, then we will use them in field research to see how well they work in that arena. With our brain mapping system, we can determine the brain areas of maximal response and use those sites when recording in operational settings.

PSYCHOPHYSIOLOGICAL ASSESSMENT TEST SYSTEM (PATS)

The PATS is almost completed and is the newest version of our physiological test battery which is superior to our older system, the Neuropsychological Workload Test Battery (NWTB). The primary areas of enhancement are: user interface, added tests, analysis tools, data storage capabilities, and resident statistical analysis capabilities. The user interface was designed with both the inexperienced user and the simulation environment in mind. Using the graphics capabilities of the Macintosh II computer, a very extensive set of interface screens have been implemented. They take the user through the steps necessary to set up a data collection session. This includes specifying the individual tests, determining their parameters, and establishing the conditions which start and stop each test, see Figure 21. The available tests include, auditory and visual Sternberg memory tasks, auditory and visual rare event tasks, auditory and visual continuous performance tasks, visual pattern reversal, auditory brain stem response, a tracking task, a visual monitoring task and a simple flash. We have added a user-defined cognitive task in which the

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user can, within the limits of the shell, design a task using
visual and auditory stimuli. This feature will be very useful
to the user. Several analysis tools have been added. These
include digital filtering, single trial evoked potential
analysis, improved data editing and manipulation.
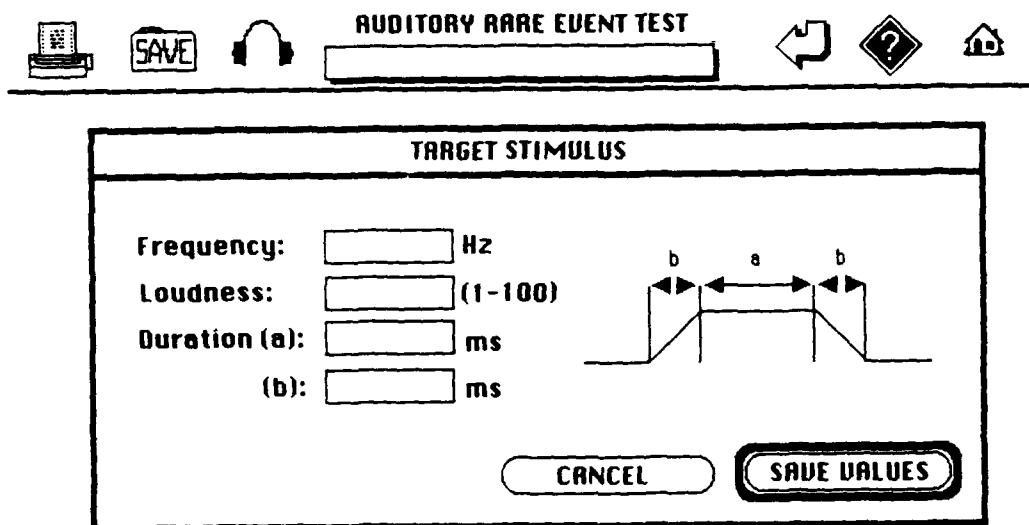
Figure 21. Sample PATS screen for establishing the
parameters for auditory stimuli in the rare event test. The
user quickley goes though several screens such as this to
establish the parameters for each test.

By implementing a laser disk, the user will be able to
collect and store up to 8 hours of 16 channels of analog and
additional digital data. Prior to the advent of the laser
disk, this amount of data could not be easily stored digitally
in a small package. We have found a very good statistical
package that will be resident on the PATS. The reduced data

will be organized so that it can be directly submitted to the statistical package. This will greatly reduce the data handling required, speed up analysis, and omit the errors of the extra data handling now required to get it from one machine to another. Statistical analysis can now be performed at the site of data collection enabling the user to make on the spot decisions about the next data to collect on the basis of the current results. The users manual will provide the information required to operate the system.

The PATS has been developed on the basis of our experience and others experience with the NWTB. It has been designed to meet the needs of the novice and experienced user in the field (simulator) and laboratory environments. We have spent a great deal of time on the user interface and the other enhancements. A number of potential users have already expressed interest in using the PATS. Preliminary versions have been demonstrated at the Human Factors Society and the Aerospace Medicine Association Annual Meetings.

FUTURE DIRECTIONS

FIELD RESEARCH

We need a larger data base of flight data so that we can begin making generalizations about physiological data. The more situations that we cover, the better we will be able to see both the commonalties across missions and the unique qualities of individual missions, crew positions, and aircraft.

This will permit us to provide more useful information to designers and evaluators of new systems. This data base will also be extremely useful for the evaluation of current systems and solving problems that arise with these current systems. We should continue data collection with routine training missions with additional types of aircraft, but also acquire data representing extremes such as night in-air refueling, reconnaissance and long-haul transport missions.

When collecting data during operational missions, we are restricted to the available missions of the flying unit. By careful selection of aircraft and mission type we can accomplish a great deal. However, we need to have more control over some flights so that we can test important facets of our techniques. For example, the sensitivity of the various physiological measures needs to be determined. This requires greater control over what the pilots are doing than is possible during one typical operational mission. In order to accomplish these goals, we will have to utilize other aircraft and pilots in situations where we can design the missions with the types and levels of workload that are required to provide us with the data we need.

Probe and other evoked potential, as well as ongoing EEG analysis, methods should be used in flight studies to ascertain their utility. The capability to capture timing signals from aircraft displays and auditory systems should be developed so that time-locked brain activity in response to these "naturally occurring" stimuli can be used to determine workload and state.

LABORATORY RESEARCH

Since flight and other Air Force functions are by their nature multiple tasks, we need to conduct laboratory research with multiple task paradigms. Historically, performance and psychophysiological laboratory research has used single tasks or dual task paradigms. These provide a great deal of experimental control and permit unequivocal interpretation of the effects of the variables manipulated. Most real world jobs involve multiple task situations due to the nature of the jobs. This presents a problem of experimental control and analysis; but, if we are to understand the nature of these situations, these issues must be dealt with. The measurement of workload in multiple tasks was addressed in three recent chapters in the book Multiple Task Performance edited by Diane Damos (Wilson & Eggemeier, 1991; Eggemeier & Wilson, 1991; Eggemeier, Wilson, Kramer & Damos, 1991). The reviews of the literature for these chapters emphasized the need for research with multiple tasks and the problems of interpolating from single or dual task results to the multiple task situation. Batteries such as the NASA Multiple Attribute Task Battery will be used to provide "real world" types of environments to collect data. While not a substitute for actual "on the job data," these batteries do permit the initial statistical and theoretical examination of more real-world-like situations. This is necessary because control over the environment is needed to understand the complex interactions of events that take place in the operational environment. The use of multiple task situations

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will require rethinking of our assumptions and methodologies of research. We no longer have absolute control as we did in the single task situation. This brings with it many problems, but problems that must be faced if we are to advance to the applied world. Some see this as an impossible situation, others see it as a challenge to our creativity.

With the advances in imaging technology, it is now possible to study the spatial distribution of electrical, magnetic and metabolic activity in the intact human brain. This permits us to study the spatial as well as temporal pattern of information flow in the brain. By combining these imaging techniques and by utilizing the best one for a given problem, we are on the threshold of being able to make large advances in understanding how the brain processes information. By developing functional brain atlas, we will better understand how the human brain functions when it is engaged in cognitive activity. Not only will we be able to establish which areas of the brain are used for different cognitive functions, but we will be able to map the temporal pattern of activity associated with different tasks and cognitive functions. We can use this knowledge to design better displays and to monitor workload and operator state. Having the capability to select from these very powerful imaging techniques would permit the rapid pursuit of our goal of better understanding of brain information processing and the application of this information to Air Force needs.

Single and few trial evoked potential techniques should be

explored further. Our airborne studies have shown that brain evoked potentials can be recorded from pilots. Better methods of collecting and processing this data are required so that this technique can be applied in more situations. We are also working on a device to process cardiac, respiration, eye blink, evoked potential and EEG spectral data in near real-time. The device will detect the relevant parameters from the raw data, such as cardiac R-waves, and will provide this information to an on-line classifier that will classify subject workload or state and will give this information to the user or system being operated.

One component of the advancement of workload and subject state measurement is to standardize methodologies. This was the goal of the AGARD Working Group on "Human Performance Assessment Methods." This group established the AGARD Standard Tests for Research with Environmental Stressors (STRES) battery as a standardized set of seven tests that could be used by researchers in the NATO countries and established a data base for data exchange using this battery (Farmer, et al, 1989). CSERIAC and Ergodata, in the United States and France, respectively, are repositories of this data base. At our instigation, a similar working group has been established by AGARD to standardize psychophysiological measures. This will stimulate more laboratories to use these methods and will facilitate data exchange by providing standard recording and analysis techniques.

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